Capacity Utilization and Productivity Analysis in the Canadian Food Manufacturing Industry

by

Zili Lai

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ABSTRACT

CAPACITY UTILIZATION AND PRODUCTIVITY ANALYSIS IN THE CANADIAN FOOD MANUFACTURING INDUSTRY

Zili Lai
University of Guelph, 2015

Advisor:
Prof. Getu Hailu

Food processing is Canada’s largest manufacturing employer, accounting for 236,000 jobs and the second largest manufacturing industry overall by revenue. However, the industry has recently experienced a considerable number of plant restructuring and a diminishing national trade surplus in processed food. The purpose of this study is to measure capacity utilization and multifactor productivity in order to examine the contribution of capacity utilization to change in productivity in the Canadian food manufacturing industry. I use data envelopment analysis and the Malmquist productivity index to measure capacity utilization and multifactor productivity in food manufacturing industry over the period 1990-2012 at provincial level. The results show every province (except Newfoundland) experienced a slowdown in multifactor productivity growth since 2000, the extent of which varies considerably by province. Capacity under-utilization is one important reason for Atlantic and Prairie Provinces’ productivity growth slowdown.
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Chapter 1

Introduction

1.1 Motivation

Food processing is Canada’s largest manufacturing employer, accounting for 236,000 jobs, and the second largest manufacturing industry overall with $88 billion in revenue in 2011 (Sparling and Chenny, 2014). While the current environment offers opportunities for the agriculture and food processing industries, the sector also faces a number of significant challenges including increased prices of unprocessed agricultural commodities, increasing concentration among domestic food retailers, environmental regulations, foreign competition and exchange rate volatility. The diminishing trade balance in the Canadian food processing industry since 2000 could signal domestic food processors lack competitiveness (Seguin and Sweetland, 2014) and raises questions about the industry’s long term viability. In order to survive an increasingly competitive global and domestic environment, many processing firms have gone through painful restructurings. While Alberta, Saskatchewan, Manitoba and Nova Scotia saw net openings, a number of plants in Ontario and Quebec were recently closed, relocated, or reorganized (Sparling and LeGrow, 2014). Ontario’s provincial government faced with manufacturing job losses in autos and other durable goods, is aggressively pursuing food processing industries. In a recent news release (November 27, 2014), “Premier Kathleen Wynne honored local agri-food industry innovators and announced a new Growth Steering Committee to help drive
agri-food industry growth and create jobs across the province.”¹ This commitment presents an opportunity for Ontario’s food processors and signals the government’s desire to generate higher growth in the agri-food industry.

Porter (1990) emphasizes the productive use of resources in a nation as a good measure for competitiveness. For this reason, improvement in productivity² and efficiency³ is a major focus of efforts to enhance the competitiveness of Canadian food processing firms. Understanding the sources of changes in productivity is also important for both predicting the future competitiveness of the industry and developing policy. The purpose of this paper is, therefore, to examine the productivity of the food processing industry in Canadian at the provincial level and to identify the sources of productivity growth over the period 1990 to 2012. To achieve this purpose, the relative levels and changes of multifactor productivity measured and compared at the provincial level. Also, the level of capacity utilization, pure technical efficiency, and scale efficiency, are measured and compared across provinces and over time within a province.

1.2 The Economic Problem

Previous research has analyzed the multifactor productivity performance of Canadian business sectors and manufacturing industries. Sowlati and Vahid (2006) estimate the Malmquist productivity index for the Canadian wood manufacturing sector

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² Productivity is a measure of how much goods or services can be produced from a given set of inputs used (Syverson, 2004).
³ Efficiency is a measure of observed output and maximum or optimal output (Fried et al., 2008).
CHAPTER 1. INTRODUCTION

from 1994 to 2002 and decompose the productivity growth into technical change and technical efficiency change. Sowlati and Vahid find productivity growth in this Canadian manufacturing sector is driven by technical progress. Hamit-Haggar (2009) evaluate eighteen Canadian manufacturing industries’ multifactor productivity growth and investigate the sources (i.e., technical change, technical efficiency change, allocative efficiency change and scale efficiency change) of productivity growth over the period 1990-2005. Hamit-Haggar find research and development (R&D) and trade openness both positively impact productivity growth. Baldwin et al. (2013) employ plant level data to examine labour and multifactor productivity growth in the Canadian manufacturing sector from 1990 to 2006. Baldwin et al. find an aggregate multifactor productivity slowdown led to considerable declines in labour productivity after 2000.

Despite its importance to the Canadian economy, there is limited literature focusing on the food processing industry. Research involving the productivity of the Canadian food processing sector typically do so at a national level using an intra-industry comparison across manufacturing sectors. However, manufacturing in different sectors (e.g. automobiles, textiles, chemicals, etc.) is often characterized by significant heterogeneity in production technologies. As a result, these productivity measures may not be useful in the specific context of the food processing industry. Furthermore, previous research the importance of inter-country differences. For example, Syverson (2011) find large and persistent differences in productivity across countries and regions for most industries. While specific to a Canadian context, Avillez and Ross (2011) find considerable variation in labour and multifactor productivity across provinces. Therefore, this thesis focuses on the food processing industry across regions within Canada.
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The OECD (2001) advocates productivity measurement should be conducted at an industry level because methods of productivity measurement rely on the theory of production. Chang-Kang et al. (1999) adopt a cost function model to investigate the productivity growth in Canadian and U.S. food manufacturing sectors, and find Canada was outperformed by the U.S., which they attribute to higher material prices. In the global market, lower productivity performance would likely reduce the cost competitiveness of Canadian processed food products. Indirectly it could also limit the growth of Canada’s primary agriculture industry because the food and beverage processing industry is the largest destination for Canadian primary agriculture productions, accounts for 38% of the total agriculture production in 2010 (AAFC, 2015). With this in mind, this study is set to 1) estimate the multifactor productivity performance within the Canadian food processing industry at the provincial level, 2) to examine whether multifactor productivity growth varies across provinces, and 3) to examine the contribution of changes in capacity utilization to changes in multifactor productivity.

Canadian food processors are facing pressure from rising raw agricultural commodity costs. According to AAFC (2015) document 38% of primary agriculture products were distributed to the food processing industry in 2010. For example, grain and livestock are the two main ingredients of grain milling and meat processing industry, respectively. During 2003-2013, the farm product price index (FPPI) for grain (livestock) increased by 49% (34%) while milled grain (processed meat) prices in the industry price index (IPPI) increased by only 34% (8%). In addition to the downstream pressure,

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4 Capacity utilization refers to the ratio of actual output to the maximum or potential capacity output from a quasi-fixed inputs. Johansen (1968, p.52) defined capacity output as “…the maximum output that can be produced from a specific bundle of the quasi-fixed inputs even where there is no restriction on the availability of variable inputs.”

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CHAPTER 1. INTRODUCTION

upstream food retailers have unprecedented power to push processed food prices down: in 2013, according to AAFC (2010), 60% of the grocery retail business was concentrated into three firms (Loblaw’s, Sobey’s and Metro Inc.).

The global economic environment for Canadian food processors has changed dramatically since the 1990-1999 period. The free trade agreement between the U.S. and Canada signed in 1990 and the North American Free Trade Agreement (NAFTA) signed in 1994 simulated the demand for Canadian merchandise. The average annual tariff reductions in manufacturing sector between the U.S. and Canada in pre-2000 was 0.6% (Baldwin et al., 2011), but has remained unchanged since 2000. Moreover, the value of Canadian dollar shows different trends before and after 2000. The Canadian dollar depreciated from C$0.86/US$ in 1990 to C$0.67/US$ in 2000. Since 2002, the Canadian dollar started to appreciate and peaked to C$1/US$ in 2012. As the primary destination for goods manufactured in Canada, the US-Canada foreign exchange rate directly effects the demand for and competitiveness of Canadian manufactured goods. The unflavored support provided between the U.S. and Canada in the post-2000 period lead to a slowdown in labour and multifactor productivity growth in the Canadian manufacturing sector.

1.3 The Economic Research Problem

Hamit-Haggar (2009) point out that exploring sources of productivity change may help to identify Canada’s productivity problems, develop policies to reverse the situation, and consequently reduce the productivity gap with other countries. The literature decomposes
CHAPTER 1. INTRODUCTION

change in productivity into three main sources: pure technical efficiency change, technical change and scale efficiency change (Coelli et al. 2005; Kumar and Basu 2008; Melfou et al. 2009). Capacity utilization change is another factor that affects productivity growth (Basu, 1996; Basu and Fernald 2001; Gu and Wang 2013), however, few studies examine the contribution of capacity utilization change to productivity.

Capacity utilization is an important economic indicator which not only explains the relationship between actual output and maximum or potential output, but also implies the level of market demand. Over- and under-utilization of plant capacity can reduce plant competitiveness by increasing operating costs (Seguin and Sweetland, 2014). Chang-Kang et al. (1999) argue the failure to fully undertake extensive cost-cutting practices is one reason for the lag in the Canadian food processing industry’s productivity. Gu and Wang (2013) find Canadian manufacturing industries’ productivity slowdown is largely due to a decline in capacity utilization. Measuring the level of capacity utilization and examining the effect of capacity utilization change on productivity growth is, therefore, an important step towards improving the aggregate food processing sector’s productivity growth. Most previous studies used survey methods or ad hoc proxies to measure capacity utilization, such as unemployment rates (Solow, 1957), growth rate of materials (Basu, 1996), or hours worked per worker (Basu and Fernald, 2001). In this study, I employ a method proposed by Fare et al. (1989), this method builds on the technical (engineering) concept of capacity utilization introduced by Johansen (1968, p.52) and allows to estimate the level of utilization rate by non-parametric approach.

5 Capacity output can be defined either economic based (Cassel 1937, Klein 1960, Berndt and Morrison, 1981) or technical based (Johansen, 1968). This study I adopt the latter one.
6 When market demand grows, capacity utilization will rise. By contrast, if demand weakens, capacity utilization will slacken.
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without requiring information on input and output prices. Johansen defines the capacity utilization as “…the maximum output that can be produced per unit of time with existing plant and equipment provided the availability of variable factors of production is not restricted.”

Compared to other sectors, the Canadian food processing industry experienced relatively low fluctuation in capacity utilization over the last 30 years (Ross, 2011). However, the average capacity utilization was lower than the aggregate manufacturing industry. What is unknown is the variation in capacity utilization across Canadian provinces. This study aims to estimate capacity utilization for each province, and measure the effect of changes in capacity utilization on each province’s productivity growth.

In sum, this thesis is motivated by a lack of information about multifactor productivity growth in the Canadian food processing industry and its sources of change at the provincial level. Specifically, I will examine the changes in technical, scale efficiency, pure technical efficiency relative to full capacity\(^7\), and net capacity utilization\(^8\). This thesis will not only document the food processing sector’s productivity performance in each province, but will also identify productivity problems with the aim of improving competitiveness in an effort to ultimately increase long-term standards of living.

\(^7\) Pure technical efficiency relative to full capacity measures the difference between actual output to capacity output. It is caused by both inefficient utilize the variable inputs and fixed inputs. Deb (2014) defines it as gross capacity utilization. In order to avoid the confusion between pure technical efficiency and pure technical efficiency relative to full capacity. I use gross capacity utilization in the following paper. The detail information can be found in Chapter 5.

\(^8\) Deb (2014) divides capacity utilization into net capacity utilization and gross capacity utilization. Net capacity utilization measures the difference between frontier output and capacity output. It is caused by only inefficient utilize the fixed inputs. For convenience, I use capacity utilization instead of net capacity utilization in the following papers.
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The results show every province (except Newfoundland) experienced a slowdown in multifactor productivity growth since 2000, the extent of which varies considerably by provinces. The largest food processing province, Ontario experienced a considerable decline in productivity in the post-2000 period with a 2.2% annual rate of decline. The level of capacity utilization rate for each province’s food processing industry is also different. The change in capacity utilization contributes considerable effects to productivity growth in the Atlantic and Prairie Provinces.

1.4 Purpose and Objectives

The purpose of this study is to estimate the multifactor productivity performance for the Canadian food processing sector at provincial level, and to examine the contribution of variation in capacity utilization to productivity changes. The specific objectives are: (1) to provide a historic overview of the Canadian food processing industry’s economic condition and to review the concepts and measurements of productivity and capacity utilization; (2) to summarize the aggregate provincial level data of the food processing sector from Statistics Canada over 1990-2012; (3) to measure the annual level of capacity utilization, pure technical efficiency and scale efficiency for each province using data envelopment analysis (DEA); 4) to measure aggregate multifactor productivity growth (MFPG) for food processing sector at 3-digit NAICS level and five selected food processing subsectors at 4-digit NAICS level (i.e., animal food, meat food, seafood, dairy and grain milling); and (5) to decompose the MFPG into four sources of productivity change (i.e., technical change, scale efficiency change, gross capacity utilization change...
and capacity utilization change), and to estimate the contribution of capacity utilization to the MFPG variation using a panel regression.

1.5 Outline of this Study

Chapter Two provides a brief historic overview of economic conditions for the Canadian food processing industry and the operational environment for domestic food processors. Chapter Three reviews previous literature about productivity, efficiency and capacity utilization analysis. Chapter Four introduces the concepts and frameworks used to estimate productivity and efficiency, the concept of output orientated distance function, as well as the theoretical framework of both technical based and economic based capacity utilization. Chapter Five shows the empirical models used to calculate different efficiency indicators, the Malmquist productivity index, and the decomposition of productivity changes. Chapter Six details the data collection and organization. Chapter Seven gives a preliminary analysis of the Canadian food processing industry using descriptive statistics and then present the outcomes obtained from empirical models. Chapter Eight concludes the thesis with a summary of previous chapters as well as a discussion of the study’s limitations and policy implications.
Chapter 2

Industry Background

2.1 The Canadian Food Processing Industry

2.1.1 The Food Processing Industry Revenue

The food processing industry is the second largest Canadian manufacturing industry after the transportation equipment manufacturing industry with over $88 billion revenue in 2011 (Sparling and Chenny, 2014). Unlike other manufacturing industries, the food processing industry experienced stable revenue growth over the last decade. Figure 2.1 shows that the total revenue for the Canadian food processing industry over the period 1992 to 2012. The nominal revenue generated from processed food business has nearly doubled from $47.39 billion in 1992 to $89.32 billion in 2012. During the same period, the food processing industry’s real revenue has only increased by 29% between 1992 and 2012: from $47.39 in 1992 billion to $61.82 billion in 2012. Additionally, the growth of real revenue in pre-2000 period is faster than the post-2000 period, with an annual rate of 2% and 0.7%, respectively. The food processing industry is also the largest manufacturing employer. While increased automation resulted in extensive job losses in most manufacturing industries, the food processing sector kept a relatively stable number
over the last decade (Sparling and Cheney, 2014). According to Statistics Canada (CANSIM table 301-0006), the number of total employees in food processing sector realized a minor increase from 232,735 in 2004 to 234,563 in 2012. As a result of the relatively high intensity of labour, the revenue per employee in the food processing industry is lower than other manufacturing industries.

![Figure 2.1: The Canadian food processing industry’s total revenue, 1992-2012](image)

Source: Statistics Canada CANSIM database

### 2.1.2 The Food Processing Industry Cost and Margin

While the Canadian food processing industry showed a steady upward trend in its revenue over the last decade, it faced a considerable pressure from rising raw material costs. Figure 2.2 shows the cost share of the four main aggregate production inputs from 1990 to 2012. The cost of raw materials and energy experienced an upward trend over the
CHAPTER 2. INDUSTRY BACKGROUND

period 1990-2012. The cost of materials and supplies is the major expense of processed food, with an average of 67% of the total cost. We can see materials and supplies cost increased 5.6% from 64.1% in 1990 to 69.7% in 2012. During the same period, the cost of energy, water utility and vehicle fuel increased from 1.5% to 2.2%. Compared to the cost of materials and energy, the salaries and wages and the cost of capital stock experienced a decline over the last two decades. With an improvement in manufacturing technology, labour input and capital input reduced by 3%, respectively.

Figure 2.2 Cost share of aggregate production inputs for the Canadian food processing industry at provincial level, 1990-2012

Source: Statistics Canada CANSIM database
The cost of materials and supplies as mentioned above, is the major expense in food processing industry with an average of 67% of the total cost. Thus, an increase in the price of materials and supplies will considerably affect the food processors’ margin. Figure 2.3 shows the change in IPPI and FPPI for the Canadian food processing industry from 1992 to 2012 (base year 1992=100). IPPI represents the price index for processed food, while FPPI represents the price index for raw materials, because primary farm products are the principle raw material for food processing. We can clearly see IPPI increased by 62.5% and FPPI increased by 44% over the 20 year period. Thus FPPI rose faster than IPPI, in particular after 2007. Interestingly, IPPI grew at a relatively stable rate while in contrast the growth of FPPI is pro-cyclical and very unstable. Since 2007, FPPI exhibited a higher number than IPPI and is approximately 10% higher than IPPI in 2012. The effects of an increasing IPPI-FPPI gap and a volatile farm product price could place considerable pressure on food processors’ margins.

According to Statistics Canada, real value-added in the Canadian food processing industry increased by 9% from $16.48 billion in 1992 to $17.98 billion in 2012 (base year=1992), and peaked at $19.85 billion in 1999, 20% higher than in 1992. Since 2000, the number of real value-added started to fluctuate and ended at $17.98 billion in 2012, 9% less than the 1999 peak. Grier and Sweetland (2014) note the pressure on domestic food processors’ margin is extensive because of forces such as retailer concentration. Retailers have strong buying power to hold the food retail price unchanged in order to keep their price competitiveness; as a result the higher cost of processed food may not transfer proportionately upstream.
2.1.3 International Trade of the Canadian Food Processing Industry

While the steady increase in the price of inputs shrinks food processor margins, the international trade environment for Canadian processed food is also challenging. Trade balance is an important economic indicator indicating a given sector’s competitive power in the global market. Figure 2.4 displays the import and export value of Canadian processed food between 1992 and 2012. First, exports steadily increased from $5.8 billion in 1992 to $17 billion in 2002. Since then it has fluctuated, peaking at $24 billion in 2012. Compare to exports, imports of processed food indicate a relatively stable growth trend from $5.8 billion to $21 billion over the same period. The trade balance changed from deficit to surplus before 2000. The trade surplus peaked at $6 billion in 2004, but the level of surplus has trended downwards since then: even though there is a
recovery after 2009, the overall change of trade balance has fallen in the post-2000 period. The decline in trade surplus implies a reduction in the demand for Canadian processed food, meaning the competitiveness of Canadian food processors has declined.

![Figure 2.4 Exchange rate and the trade balance of Canadian food processing industry, 1992-2012](image)

**Source:** Statistics Canada CANISM database

One reason why trade surplus has declined since 2004 is the increase in the relative value (appreciation) of the Canadian dollar. In the context of international trade, firm competitiveness is enhanced if the domestic currency (i.e. currency of costs) experiences a real depreciation, or equivalently, if foreign currency (i.e. currency of revenues) experiences a real appreciation (Shapiro 2006). Figure 2.4 illustrates the historical
exchange rate of the Canadian dollar relative to the U.S. dollar from 1992 to 2012. Clearly, the value of Canadian dollar depreciated in the beginning: from 0.83 in 1992 to 0.64 in 2002. Then, the Canadian dollar started to appreciate, reaching parity (1.00) in 2012. The appreciation of the Canadian dollar has had significant effects for the economic environment of Canada’s food processing industry. Trading partners, like the U.S. tend to purchase less from Canada due to the currency-related price increase for Canadian merchandise. Canada is heavily reliant on the U.S. as a trading partner, although recently it has attempted to diversify its trade relationships and the share of Canadian trade going to the U.S. decreased from 75% in 2003 to 67% in 2005 (Seguin and Sweetland, 2014). Improving the productivity and competitiveness of domestic food processors is a key for Canada to build long-term relationships with other countries and achieve success in international markets.

2.2 Structure Characteristics across the Canada Provinces

2.2.1 Productivity in the Total Manufacturing Industry

Avillez and Ross (2011) summarized the characteristics of the Canadian manufacturing sector’s labour productivity and multifactor productivity performance across provinces between 1997 and 2007. Alberta had the highest relative labour productivity than other provinces (followed by Quebec, Ontario and British Columbia), whereas Ontario and Quebec experienced the fastest growth rates in labour productivity. In terms of multifactor productivity, British Columbia, Ontario, Alberta and Quebec outperformed other provinces. The manufacturing industry’s multifactor productivity in
CHAPTER 2. INDUSTRY BACKGROUND

Ontario is outstanding, while its average productivity growth rate and labour productivity performance are lower than the national average. British Columbia had the largest growth in multifactor productivity of approximately 4% between 1997 and 2007, reflecting relatively high capital intensity. In contrast, the improvement in Quebec’s manufacturing productivity performance was mainly driven by high growth in labour productivity. Manitoba and Saskatchewan experienced an above average growth rate in multifactor productivity. Meanwhile, the Atlantic Provinces experienced a relatively downward trend in productivity performance and Alberta did not perform well in its productivity performance due to falling productivity in mining and oil extraction.

This section outlined productivity for the total manufacturing sector at provincial level over 1997 to 2007. Although not specific to the food processing industry, it provides background information on the (often large and persistent) productivity differences across provinces. It also indicates the source of productivity changes can vary by province.

2.2.2 Operational Environment in the Food Processing Industry

The recent closures, relocations and reorganization of a number of food processing plants in Ontario and Quebec (such as H.J. Heinz Co., Smucker’s, Kellogg, and Kraft Food Groups Inc.) raise attention to the importance of remaining competitive for local food processing firms. Sparling and LeGrow (2014) summarize the plant closings, openings and investments activities in the Canadian food processing industry at a provincial level between 2006 and 2014. Their main result demonstrates that a total number of 143 Canadian food plants shut down during this period. At the same time, 63 new plants
CHAPTER 2. INDUSTRY BACKGROUND

opened and 67 companies announced major investments. Most plant closures were made by multi-plants companies with the apparent intention of reorganizing and relocating their plants (often to other justifications) to increase their scale and achieve higher efficiency.

Figure 2.5 displays the primary\(^9\) and secondary\(^{10}\) processing plant activities in Canada across provinces between 2006 and 2014. Ontario and Quebec are two provinces with the largest number of the food processing plants in Canada. Figure 2.5 shows that Ontario and Quebec experienced a large number of plant closures in the last decade, especially Ontario. The total number of closures in Ontario was 59 compared only 26 new plant openings. The large net loss of plants effects Ontario’s food processing sector and may

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\(^9\) Primary processing involves the first level of processing for farm gate products.

\(^{10}\) Secondary processors use the output from primary processing and turn it into further processed products.
reveal a lack of competitiveness. Compared to Ontario, plant closures and openings are relatively balanced in Quebec in both primary and secondary sectors with more openings than closures. It is also interesting to note many plants have been relocated to Alberta, Saskatchewan, Manitoba and Nova Scotia, which may have been induced by relatively low cost of inputs, land, or other factors. For example, Ashton et al. (2014) concluded Manitoba is attractive to the food processing sector because of the availability and low cost of raw products, access to quality water, and central location for exporting products. There is a growing grain and oilseed milling industry Saskatchewan because Saskatchewan harvests the largest number of grain products including grain, canola and barley which the main sources of biofuels, such as ethanol, biodiesel and biogas (Western Economic Diversification Canada, 2010). Overall, Ontario is the only province with a significant net loss of food processing plants. If Ontario’s food processors want to keep their leading position, they have to implement better management practices to enhance their productivity and efficiency, which could be facilitated by support from federal and provincial policies.

2.3 The Situation of Capacity Utilization

Figure 2.6 compare capacity utilization rates\textsuperscript{11} in the Canada from 1990 to 2012 for all industries (total industry), manufacturing sectors, and the food processing sector. The average capacity utilization in total industry is 82%, where 82% capacity utilization has been treated as a threshold level for inflationary pressures in Canada (Lefteris and

\textsuperscript{11} The rate of capacity use is the ratio of actual output to potential output. The measures of actual output are the measures of real gross domestic product (GDP) at basic prices, seasonally adjusted by industry (survey record 1301). The measures of potential output are derived from the Fixed Capital Flows and Stock survey (survey record 2820).
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Theologos, 2006). However, the total industry capacity utilization is volatile during these years and volatile capacity utilization may present a challenge for stable economic development. The manufacturing sector follows a similar volatile pattern as total industry. Compared to the total industry and the total manufacturing industry, capacity utilization in the food processing sector was relatively stable over the period. But, its average capacity utilization rate of 80% is lower than the other two aggregate.

In all three cases, capacity utilization has declined since 2000. While total industry and the manufacturing sector have somewhat recovered since 2009, the food processing sector saw only a short recovery between 2007 and 2008 after which it started to decline. Overall, the relatively lower level of capacity utilization for the food processing industry signaled there is room for improvement in the utilization of capital. Consequently, better capacity utilization may help food processors achieve higher productivity and profits.

Figure 2.6 Industrial capacity utilization rate by NAICS, 1990-2012

Source: Statistics Canada CANISM database.
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2.4 Summary

At the same time as food processors faced significant challenges such as rising raw material prices and higher concentration amongst food retailers, real revenue only increased slightly over the past 20 years. Additionally, increased global competition and the appreciation of the Canadian dollar led to a decline in trade balance over time. Maintaining competitiveness in domestic and global markets in spite of these challenges could be achieved with higher productivity or higher and more stable capacity utilization. Identifying the productivity problems/gaps and narrowing the gap between provinces could also improve the standing of Canada’s food processing sector.
Chapter 3

Review of Literature

3.1 Productivity

3.1.1 The Concept of Productivity

Productivity is an important economic concept used to measure the economic performance and competitiveness of a production unit, such as a firm, an industry or a country. Productivity measures how much of a good or service can be produced from a given set of inputs (Syverson, 2004). Productivity is a key determinant of long-term living standards because of living standards are determined by the availability of goods or services and, given limited resources, improving productivity is the only way to increase outputs (Backman and Gainsbrugh, 1949). Productivity is also an indicator of social welfare: higher productivity can generate more options for people to choose from, consequently improving overall welfare. In the recent study by Basu et al., (2009), they argue multifactor productivity is the correct tool to measure consumer welfare.

In the short-run, consumers benefit from less expensive products. In the long-run, labour earns a higher real wage. Wysokinska (2003) also notes higher productivity allows a firm to generate more funding for development and expansion. Through this mechanism higher productivity leads the firm or country to become more competitive in
the domestic and world markets. Therefore, productivity improvement is an important aspect of a firm’s or country’s competitiveness.

3.1.2 Productivity Index

There are two different ways to describe a firm’s productivity performance: productivity level and productivity change. Productivity level measures productivity performance in a single period, while productivity change measures the change in productivity level from one period to another. A productivity change index allows a comparison of productivity over time. Various approaches can be used to estimate a firm’s productivity index. For example, the Hicks-Moorsteene productivity index proposed by Hicks (1961) and Moorsteen (1961); the Luenberger productivity indicators introduced by Chambers (1996); and the Malmquist productivity index (Caves, Christensen, and Diewert, 1982). The Malmquist productivity index is a commonly used index for comparing multifactor productivity over two periods because it does not require any price information and can be decomposed into different sources of productivity changes. The Malmquist productivity index is calculated using the distance functions\(^\text{12}\) of a production unit at two different periods relative to a reference production frontier. The distance function can be measured in either output orientation or input orientation. Output orientated distance function is defined as the maximum possible output vector by a given input vector used under a reference technology. Input orientated distance function is defined as the minimum necessary input used in production by a target output vector produced under a reference technology. The choice of orientations depends on the objectives of the study.

\(^{12}\) Distance function measures the ratio of production point to production possible frontier.
One objective of this study is to estimate the capacity utilization where capacity output is the maximum or potential output using a quasi-fixed input\(^{13}\). Thus, this thesis uses the output orientated distance function.

### 3.2 Measurement of Productivity and Efficiency

Data envelopment analysis (DEA) and stochastic frontier analysis (SFA) are commonly used approaches to measure productivity and efficiency. DEA uses non-parametric and deterministic methods, while SFA uses parametric and stochastic methods. Each method has its own advantages and disadvantages.

Because DEA is non-parametric and deterministic method it does not require users to specify the functional form and statistical regression approaches. As a result, no restrictive assumptions about technology have to be made, except convexity. Moreover, there is no need to prescribe weights to each input and output (Copper, Seiford and Tone 2006). DEA uses observed input and output to build an upper bound of a production possibility set without a functional form or significance test. Outliers in the data set can lead to imprecise measurements of productivity.

Compared to DEA, as a parametric and stochastic method SFA seems more comprehensive. The choice of a production function is necessary (such as Cobb-Douglas, Quadratic or Translog function), which allows for richer specifications and hypothesis testing. Further, production elasticities are readily available to explain the relationship

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\(^{13}\) Quasi-fixed input is the production input that cannot be adjusted to the equilibrium level in the short run because of constraints, such as adjustment costs (FAO, 1999).
between variables because the parameters have been estimated and are explicit. The other advantage is in accounting for the effects of data noise, which arise from the inadvertent omission of relevant variables, such as uncontrollable environment. DEA ignores such effect and a result may be an unreliable measurement of productivity and efficiency (Hjalmarsson et al. 1996, Coelli et al. 2005). Empirically, Hjalmarsson et al. (1996) did a comparison between these two alternative approaches based on 15 Columbian cement plants data between 1968 and 1988. They find no substantial difference in efficiency score estimation, but some variation for scale analysis.

The choice between models should be based on the purpose of the study and available data. In this study, I estimate the productivity and efficiency for the Canadian food processing industry at provincial level where the sample size, and therefore degrees of freedom, is relatively small. With small degrees of freedom, the significance of a t-test would have low accuracy. Therefore, I decide to use DEA in this study.

3.3 Productivity Dispersion

A number of previous studies have demonstrated persistent productivity differences are universal across business units and regions (e.g., Chan-Kang, et al. 1999; Syverson, 2004; Hsieh and Klenow, 2009). Abraham and White (2006) investigated the productivity performance of 453 U.S. manufacturing industries from 1976 to 1999 based on firm level data. Their results show tremendous heterogeneity and variation exists within- and between-industries. Syverson (2004) investigated productivity performance in 443 U.S. manufacturing industries (based on four-digit Standard Industrial Classification codes)
and also find evidence of large differences among within-industry plants. Specifically, the logged multifactor productivity (lnMFPQ) between interquartile range and 90th-10th percentile plants was respectively 0.29 and 0.65, where the plants at the higher percentile of the productivity distribution can produce much more output using the same amount of inputs.

Chan-Kang et al. (1999) find the Canadian food processing industry productivity lagged behind the U.S. before the 1990s. The Canadian food processing sector's productivity growth rate was also far below U.S. Specifically, they estimate processing costs in the U.S. were 22% lower than in Canada. Multifactor productivity dispersion between the Canadian manufacturing industries has been identified as main determinant of lagging labour productivity compared with other highly industrialized (OECD) countries in recent years (Hamit-Haggar, 2009). Reducing productivity dispersion would increase Canada’s overall productivity performance and reduce the gap between Canada and other developed countries. Avillez and Ross (2011) find a persistent productivity dispersion across Canadian provinces in total manufacturing industry. There is no study taken to examine the multifactor productivity dispersion in the food processing industry across Canada provinces. Although a large proportion of food processing plants are established at Ontario and Quebec, other provinces are also running sizeable food processing business. Productivity spillover effects are considered a positive externality that increase firm’s or region’s productivity growth: lower productivity firms likely attempt to emulate productivity leaders in related industries, regardless of whether they share a common input market (Syverson, 2011). Follow that logic advanced provinces may be able to transfer their knowledge and practices to relatively less productive or
efficient provinces. Measuring productivity in the food processing industry would identify which province is the leader and, consequently, assist in improving the food processing industry’s productivity overall to make domestic products more competitive in the global market.

3.4 The Decomposed Sources of Multifactor Productivity Change

To identify multifactor productivity changes, we need to distinguish which factors influence productivity growth and measure the extent of their effects. Top-down and bottom-up approaches may be used to distinguish component factors. The top-down approach starts by generating the numerical value of a productivity index (such as Malmquist productivity index) and then decomposing it into different component parts. Blak (2001) advocates for the bottom-up, which begins by identifying the sources of productivity change and then combines the factors into a multifactor productivity index. Despite the differences in these two approaches, they produce similar results (Coelli et al. 2002). In this study I use the top-down approach.

The literature decomposes productivity growth into three sources: technical change, pure technical efficiency change, and scale efficiency change. The effect of capacity utilization change on productivity growth has not been frequently investigated in the past. Further, most previous studies adopt either survey methods or ad hoc proxies to estimate capacity utilization. However, these approaches lack theoretical grounding. Fare et al. (1996) first introduced a primal approach of capacity utilization based on DEA
model. Borger and Kerstens (2000) extend the decomposition of Malmquist productivity index and allow for the changes in capacity utilization.

### 3.4.1 Technical Change

Technical change is the increase in output which can be produced from the same amount of inputs usage. In some cases, technical change includes both technical progress and technical efficiency change (Coelli et al., 2005). In this thesis, the definition of technical change is equivalent to technical progress: a neutral shift of the production function due to time alone (Heshmati and Kumbhakar, 2010). In many previous studies technical change is identified as the major driver of productivity growth irrespective of sector. For instance, Sowlati and Vahid (2006) find a frontier shift was the main reason for productivity growth in the Canadian manufacturing sector during 1994 to 2002. Similarly, Melfou et al. (2009) find technical change was the dominant determinant of productivity growth in Greek sheep sector during 1997-2002, with an average 2.4% per year. Additionally, Kumar and Basu (2008) examine productivity performance in the Indian food processing industry over 1988 and 2005. Their results suggest the Indian food processing industry performed far below its potential, which they attribute to a lack development of technological progress. Technical change can be derived by exogenous factors like research and development and innovation movements (Ross, 2011). Ross find the Canadian food processing sector’s productivity was relatively higher than other manufacturing sectors over 1961-2007. However, compared with other industrialized countries like U.S., investment in R&D was relatively low. AAFC (2015) note the
Canadian food processing industry’s R&D expenditures are lower than the total manufacturing average.

3.4.2 Pure Technical Efficiency Change

Pure technical efficiency change is also an important source of productivity changes. Pure technical efficiency means firms can produce more output with a certain amount of inputs or produce the same amount of output with less inputs with a given production technology (Coelli et al., 2005). Even though pure technical efficiency change contributes less to productivity changes compared to technical change, it’s role in promoting productivity growth is also essential. Previous research found pure technical efficiency can help enhance industry productivity performance (Ray and Desli, 1997; Coelli et al., 2005; Kumar and Basu, 2008). A comparison of pure technical efficiency change between 18 Canadian manufacturing industries undertaken by Haggar-Hamit (2009) found pure technical efficiency in food, beverage and tobacco industry experienced a downward trend after 1990. Even though pure technical efficiency realized a minor recovery around 2000, it dropped 4% over entire sample period (Hamit-Haggar, 2009).

3.4.3 Scale Efficiency Change

Scale efficiency measures the potential productivity gain from achieving a firm’s optimal size, where scale refers to the ability of large firms to spread fixed costs. Gervais et al. (2008) examined economies of scale in dairy, meat and bakery processing sectors before 2000, employing provincial level data to identify differences across provinces. The estimated scale elasticity parameters suggest bakery, meat and dairy industry performs a
significant increase return to scale in most provinces. The dairy industry presents a small decrease return to scale in Ontario and Quebec. One possible reason is supply management in dairy sector. George Morris Center (2012) also evaluated economics of scale in four-digit NAICS food processing subgroups in Canada. Their results suggest economics of scale for Canadian food processors are significantly smaller than U.S. counterparts. Restrictions on firm scale may impede productivity growth in the Canadian food processing industry.

Balk (2001) first proposed a decomposition of the Malmquist productivity index that can account for scale efficiency change. Balk uses this approach to empirical estimate the effect of scale efficiency change on productivity growth for Dutch firms between 1979 and 1992, where the results show higher scale efficiency has significant positive impacts on firm productivity growth. Similar results are found by Melfou et al. (2009) for the Greek sheep industry. The magnitude of scale efficiency change on overall productivity change is similar to pure technical efficiency changes. A number of other studies have demonstrated the significant relationship between scale efficiency change and productivity change (Coelli et al. 2005; Latruffe, 2005; Saal, Parker and Weyman-Jones, 2007).

3.4.4 Capacity Utilization Change

Capacity output is the potential or maximum output generated from existing fixed inputs, while capacity utilization is the ratio of actual production output to the maximum or potential capacity output. Capacity output can be defined by either the technical
(engineering) approach or economic approach. The technical based capacity output is defined by Johansen (1968, p.52) as: “…the maximum output that can be produced from a specific bundle of the quasi-fixed inputs even where there is no restriction on the availability of variable inputs.” Note, technical based capacity utilization rate cannot be greater than one by definition. If a firm’s capacity utilization rate equal to one, it means the firm cannot expand production at its current level of fixed inputs. Conversely, if firm’s capacity utilization rate is less than one the firm can expand production without further investment in fixed inputs.

Economic based capacity output can be classified into three different measurements. Cassel (1937) and Hickman (1964) first defined capacity output as the minimum point of the short-run average total cost curve. Klein (1960) and Friedman (1963) argue capacity output is the point of tangency between long-run average total cost curve (LRTAC) and short-run average total cost curve (SRTAC). The difference between these two definitions lies in the assumption of return to scale. In first definition, the firm is characterized by constant returns to scale and the LRTAC is horizontal. In second definition, the firm is characterized by long-run non-constant returns to scale typically with a U-shape cost curve. Both approaches measure the production gap between actual output and capacity output. Thus, these two approaches have been deemed the primal approach. Morrison (1985) developed another dual approach of capacity utilization based on a firm’s optimization behavior: cost minimization or profit maximization. Cost minimization measures the cost difference between the actual cost (measured by the firm’s shadow price of capital stock) and the optimal cost (measured by the rental price of that capital stock). In contrast to technical based capacity utilization, the economic
based capacity utilization can be greater or less than one: if a firm’s capacity utilization is equal to one, the firm has no incentive to produce more or less output; if a firm’s capacity utilization is greater than one, the firm is in over-utilization and has an incentive to produce less output; and if a firm’s capacity utilization is less than one, the firm is in under-utilization and has an incentive to produce more output.

Ultimately, the different definitions of capacity utilization require different estimation approaches. Due to limitations on available price information, I use the technical based capacity utilization in this study.

The effect of change in capacity utilization on productivity growth has attracted attention in recent years. Variation in capacity utilization is recognized as one important factor leading to pro-cyclical measured multifactor productivity growth (Basu, 1996). Gu and Wang (2013) examined the productivity growth in the 2-digit NAICS industries between 1961 and 2007 in Canada. They find that MFPG slowdown in the post-2000 period is largely due to a decline in capacity utilization. Meanwhile their results validate the opinion of Basu (1996) that capacity utilization is important in explaining pro-cyclical productivity performance. Several methods have been used to estimate capacity utilization, for instance survey-based method and ad hoc proxies (Tipper and Warmke, 2014; Basu, 1996; Basu and Fernald, 2001). However, Berndt and Fuss argue these methods lack sufficient theoretical ground, thus, the estimated capacity utilization measurements may not be appropriate.

Based on Johansen’s (1968) definition of capacity, Fare et al. (1989) first proposed a primal approach of capacity utilization based on DEA. Borger and Kerstens
(2000) further extend the decomposition of the Malmquist productivity index to allow for the effect of capacity utilization change on productivity growth. Sena (2001) used DEA to investigate the relationship between change in capacity utilization and productivity growth in the Italian manufacturing sector between 1989 and 1994, concluding the rate of capacity utilization change could provide relevant information about the evolution of aggregate demand and movements of short-term output.

3.3.5 The Importance of Identifying the Sources of Productivity Changes

Coelli et al. (2005) use both DEA and SFA to test the Malmquist productivity index for 43 rice farmers from the Philippines from 1990 to 1997. They find DEA and SFA provide similar information about the productivity index. Additionally, the effects from each decomposed component are close by both approaches (Chapter 11). In Canada, Hamit-Haggar (2009) analyzed the multifactor productivity change in 18 manufacturing industries over the period 1990-2005. Hamit-Haggar’s decomposition results suggest the primary force of productivity growth is technical change. Although pure technical efficiency change and scale efficiency change have relatively less influence, they are all crucial in determining MFP improvement. In a study of Indian food processing during 1988 to 2005, Kumar and Basu (2008) find changes in technical, scale, and pure technical efficiency contribute roughly equal amounts to productivity growth. A range of empirical work examines productivity growth that show a variety of results across different industries and countries (Fare et al. 1994, Balk 2001, and Parker et al. 2007). These findings indicate sources of productivity growth may be different for different subjects.
CHAPTER 3. REVIEW OF LITERATURE

To summarize, productivity decomposition can provide essential background information on overall industry performance. This information could be used by policymakers for projections and to promote an industry’s development via the implementation of specific policies. Hamit-Haggar (2009) suggest the study of decomposition can assist in the identification of Canada's productivity problem and consequently develop policies to reverse the situation and reduce Canada's productivity gap.
Chapter 4

Theoretical Framework

This chapter provides an overview of the production function, which is the basic framework to understanding the measurement of productivity and efficiency. I will use a simple production function graph to depict the notion of capacity utilization, technical efficiency, scale efficiency and production technology. I also provide the definitions of productivity and efficiency, as well as their theoretical framework. Then, I will introduce the output oriented distance function. Finally, I provide an explanation of both the technical and economic approach to capacity utilization.

4.1 Production Function

Production functions describe a physical or technical relationship between all physical inputs (e.g., capital, labour, energy and material) used in a production process and the maximum amount of outputs that can be obtained from the production process. Production functions map the available aggregate inputs into aggregate output such as gross domestic product (GDP) or value-added. Nelson (1964, p.575) concluded that “The conceptual basis for believing in the existence of a simple and stable relationship between a measure of aggregate inputs and a measure of aggregate output is uncertain at best. Yet
an aggregate production function is a very convenient tool for theoretically exploring some of the determinants of economic growth, and it has served as a framework for some interesting empirical studies.”

An aggregate production function\(^{14}\) can be written as:

\[
Q = f(x)
\]  

(4.1)

where \(Q\) represents output, \(x\) is an \(n \times 1\) vector of production inputs, \(f(.)\) represents the underlying production technology (implying it is not possible to produce output greater than \(f(x)\) under the current technology).

![Figure 4.1 Concepts of Productivity and Efficiency](image)

I use a production function graph (Figure 4.1) to illustrate the concept used in the study. Suppose points A, B, C and D represent four different producers. Let \(f^1(x)\) and

\(^{14}\) In macroeconomics, an aggregate production function is frequently used for a long time.
CHAPTER 4. THEORETICAL FRAMEWORK

\( f^2(x) \) be two different production frontiers that represent the maximum amount of output that can be obtained from using two different technologies. Producers A, B and C are located on the production frontier where \( T(x, Q) = Q - f(x) = 0 \). Hence, these three producers are technically efficient. When we compare the performance of producer A and B, even though both producers use the same level of input \( x \), producer B produces more output than producer A (\( Q_B > Q_A \)), and hence producer B is more productive than producer A. In this case, producer B uses a better technology in its production process. Producer C, on the other hand, has the same reference technology with producer A, and both producers are technical efficient. However, producer C is more productive than A because producer C has a better scale of operation. Specifically, we can radially expand C to \( C' \) where \( C' \) use the same amount of input \( x \) as producer A. \( C' \) produce output \( Q_{C'} \), which is greater than \( Q_A \) so that C is more productive than A. The difference between these two producers is caused by scale efficiency: C operates at a constant return to scale, whereas A operates at a decreasing return to scale. Producer D uses the same level of input \( x \) as producer A, B and \( C' \), but produces less output \( Q_D \) and is located within production frontier. Thus, producer D is less productive than the other three producers caused by technical inefficiency compared to producer A.

4.2 Multifactor Productivity

Next I introduce a unified framework for the measurement of multifactor productivity. Solow (1957) first defined rising productivity as rising output with constant capital and labour inputs. He named it a “residual” because the productivity growth is part of the
CHAPTER 4. THEORETICAL FRAMEWORK

growth that cannot be explained through capital accumulation or increased labour use. The production model is given as:

\[ Q(t) = [K(t)]^\alpha [A(t)L(t)]^{1-\alpha} \]  \hspace{1cm} (4.2)

where notation \( Q(t) \) is the aggregate output in an economy in period \( t \), \( K(t) \) is the aggregate capital input, \( L(t) \) is the aggregate labour input and \( A(t) \) is multifactor productivity. When there is no inefficiency, the observed output is equal to the maximum output for a given technology.

To measure the change in output using this model, equation 4.2 is differentiated with respect to time \( t \), giving a formula in partial derivatives of the relationships: capital-to-output, labour-to-output and productivity-to-output.

\[ \frac{\partial Q}{\partial t} = \frac{\partial Q}{\partial K(t)} \frac{\partial K(t)}{\partial t} + \frac{\partial Q}{\partial L(t)} \frac{\partial L(t)}{\partial t} + \frac{\partial Q}{\partial A} \frac{\partial A}{\partial t} \] \hspace{1cm} (4.3)

From equation 4.2, we know the derivative of \( Q \) with respect to input is

\[ \frac{\partial Q}{\partial K} = \frac{\alpha Q}{K(t)} \text{, and} \quad \frac{\partial Q}{\partial L} = \frac{(1-\alpha)Q}{L(t)} \text{, and} \quad \frac{\partial Q}{\partial A} = \frac{(1-\alpha)Q}{A(t)} \] \hspace{1cm} (4.4)

Inserting equation 4.4 into 4.3 we can get

\[ \frac{\partial Q}{\partial t} = \frac{\alpha Q}{K(t)} \frac{\partial K}{\partial t} + \frac{(1-\alpha)Q}{L(t)} \frac{\partial L}{\partial t} + \frac{(1-\alpha)Q}{A(t)} \frac{\partial A}{\partial t} \] \hspace{1cm} (4.5)

Therefore, the growth rate of output is a proportion of the change in output over the output in last year, which is given by dividing both sides of equation 4.5 by the output \( Q \). The left hand side represents the growth rate of output. The first two terms on the right
CHAPTER 4. THEORETICAL FRAMEWORK

hand side of this equation are the proportional changes in capital and labour. The last
term on the right hand side \( \frac{\partial A}{\partial t} \) gives the effect of productivity improvements, which is
defined as the Solow residual:

\[
\frac{\partial Q}{\partial t} = \alpha \frac{\partial K}{\partial t} + (1 - \alpha) \frac{\partial L}{\partial t} + (1 - \alpha) \frac{\partial A}{\partial t} \tag{4.6}
\]

The Solow residual is the component of growth not explained by the amount of capital
and labour inputs.

4.3 Technical Efficiency

When a firm in fully efficient (i.e., \( T(K, L, Q) = Q - f(K, L) = 0 \)), production inputs are
transformed into output without any waste. In the presence of inefficiency in production
process, this equality no longer holds and instead becomes:

\[
Q \leq Af(K, L) \tag{4.7}
\]

where the observed level of output Q is less than the maximum achievable output
\( Af(K, L) \). A is the neutral frontier shifter that captures changes in output not explained
by changes in the inputs through \( f(K, L) \).

Various efficiency indexes have been considered in the literature, such as
technical efficiency, scale efficiency, allocative efficiency and cost efficiency. In this
study, we focus on two main efficiency indexes: pure technical efficiency and scale
efficiency. Pure technical inefficiency is caused by inefficient utilization of production
inputs and measures the residual between the observed and maximum achievable outputs produced or observed and the minimum inputs used.

Scale inefficiency is due to non-optimal scale choice, which measures how a firm can become more productive by changing its scale of operation. Suppose the operations of a firm are below the optimal scale, then it could realize increasing returns to scale. Firms with increasing returns to scale can proportionally increase the use of inputs to obtain a greater increase in output $f(aK, aL) > af(K, L)$ (Varian 1992). If a firm moves towards constant returns to scale, it can reduce its average cost of production to reach higher productivity and competitiveness.

4.4 Output Orientated Distance Function

Distance functions play a crucial role in the process of determining productivity and efficiency. Distance functions were introduced by Malmquist (1953) to measure the ratio of the production point to the production possible frontier. There are two orientations of a distance function: inputs or outputs. An input distance function characterizes the production technology by identifying a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector, given an input vector (Coelli et al., 2005). In this study, one of the objectives is to estimate the level of capacity utilization for each provinces’ food processing industry. Capacity utilization measures the relationship between actual output produced with quasi-fixed inputs and the potential output that
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could be produced at the quasi-fixed input level if capacity were fully used. This objective lends itself best to an output oriented distance function.

The output distance function is defined on the production possible set $P(K, L)$, as:

$$d_0(K, L, Q) = \min \{\delta: \left(\frac{Q}{\delta}\right) \in P(K, L)\}$$  \hspace{1cm} (4.7)

where $K$, $L$ and $Q$ represent capital stock, labour and output vectors, $d_0$ represents the straight line distance between the origin and the observed point, and $\delta$ represents the ratio of distance to the observed point divided by the distance to production frontier from the origin. In the above formulation, minimizing the ratio of $\delta$ is equivalent to maximizing the proportional expansion of the output vector.

![Figure 4.2 Production possible set, two output and one input case](image)

Figure 4.2 Production possible set, two output and one input case

Figure 4.2 shows the concept of distance function using production possibilities curve, where two outputs $Q_1$ and $Q_2$ are produced using the same composite input $x(K, L)$.  

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Under the assumption of constant return to scale, the production possible set \( P(x) \) is formed by the production possibility frontier and its coordinate axis.

In Figure 4.2 producers A, B and C use the same amount of composite input \( x \) to produce output \( Q_1 \) and \( Q_2 \). Producer B and C produce different bundles of outputs, but both are located on the production possibilities frontier. Therefore one can say that producer B and C are technically efficient. Producer A is less efficient than producer B and C, because it produces less amount of \( Q_1 \) and \( Q_2 \) than producers B and C and as such is inside the production possible set. Here, the output distance function of producer A is equal to \( d_0 = \delta = \frac{OA}{OB} \).

The distance function is a fundamental concept that allows for the measurement of efficiency and productivity based on the production frontier. The production frontier can be constructed with econometric or mathematical programming methods. For example, the stochastic frontier analysis and data envelopment analysis are two commonly used approaches to construct production frontiers.

4.5 Capacity Utilization

Capacity output is the potential or the maximum output generated from the existing fixed input. Capacity utilization is the degree to which an economic entity actually uses its fixed productive capacity and can be defined in either technical (engineering) or economic terms. In other words, capacity utilization is the relationship between actual output that is actually produced with the quasi-fixed inputs, and the potential output.
which could be produced with quasi-fixed input, if capacity was fully used. The value of technical based capacity utilization, which can be no greater than one, implies whether a firm has the potential for greater production with the existing fixed input. The value of economic based capacity utilization, which can be greater or less than one, implies whether a firm has an incentive to change its production.

4.5.1 Technical Based Capacity Utilization

From the previous discussion of the aggregate production function, we know the maximum output $Q$ can be produced by a combination of input $x$ and a reference production technology. Therefore, the maximum producible output (or technically efficient output) by a firm using input bundle $x_0$ is:

$$Q^* = f(x_0) = \max Q: (x_0, Q) \in T, x \leq x_0$$  \hspace{1cm} (4.8)

where $Q^*$ is the maximum producible output. Therefore, the output oriented technical efficiency of the firm is

$$TE(x_0, Q) = Q/Q^*$$  \hspace{1cm} (4.9)

Johansen (1968, p.52) defined technical based capacity output as “…the maximum output that can be produced per unit of time with existing plant and equipment provided the availability of variable factors of production is not restricted.” Therefore, we need to divide the production input bundle $x$ into a sub-vector of fixed inputs and a sub-vector of variable inputs. Suppose a firm produces output by using capital stock $K$ and
labour input $L$. In the short-term, capital is quasi-fixed at $K_0$. Thus, the equation is rewritten as 4.10:

$$Q^{**} = f(K_0, L) = \max Q: (L, K, Q) \in T, K \leq K_0, L \geq 0$$  \hspace{1cm} (4.10)$$

where $Q^{**}$ is capacity output. Capacity utilization measures the gap between actual output and capacity (maximum) output where this output gap is caused exclusively by inefficient utilization of the quasi-fixed input $K$. However, when technical inefficiency is present, then part of the output gap is caused by inefficient utilization of variable inputs. Therefore, the estimation of capacity utilization will be downward biased. The biased estimate of capacity utilization is measured in equation 4.11. It is referred to as a gross capacity utilization rate ($CU_G$), which measures technical efficiency relative to full capacity (Deb, 2014):

$$CU_G = \frac{Q}{Q^{**}}$$  \hspace{1cm} (4.11)$$

To avoid biased estimation, an unbiased measure of capacity utilization rate was derived by diving the $CU_G$ by the technical efficiency score obtained from equation 4.9. Therefore, the net capacity utilization rate ($CU_N$) is measured as

$$CU_N = \frac{CU_G}{TE} = \frac{Q/Q^{**}}{Q/Q^{**}} = Q^*/Q^{**}$$  \hspace{1cm} (4.12)$$

We can reorganize from equation 4.12 that $TE = \frac{CU_G}{CU_N}$. As we know technical efficiency is less than or equal to one, thus, the net capacity utilization rate should be greater than gross capacity utilization rate.
As discussed above, the net capacity utilization rate is less than or equal to one which means if the $CU_N$ equals to one, the firm cannot produce more output using the current fixed input. Likewise, if $CU_N$ is less than one, it means that the firm has a potential to produce more output with the existing fixed input.

![Figure 4.3. Technical Based Gross and Net Capacity Utilization Rate](image)

Figure 4.3 graphically illustrates the concepts of gross and net capacity utilization rate, for the one output and two inputs case. The production frontier $f(L,K_0)$ in Figure 4.3 shows the maximum quantities of output $Q$ that can be obtained using different quantities of variable input $L$ when equipped with a quasi-fixed input $K_0$. Along the OBG segment of the curve $f(L,K_0)$, an increase in variable input $L$ (up to $L_0^*$) leads to an increase in output. After that, an increase in input $L$ does not lead to a higher level of output and the
CHAPTER 4. THEORETICAL FRAMEWORK

output either remains the same at $Q_0^*$ or decreases. Suppose a firm produces output $Q_0$ from a combination of input $L_0$ and $K_0$ and is thus located at point A. Because A is located below the production frontier, it is technically inefficient and its corresponding technically efficient point is B with $Q_0^*$ level of output. $Q_0^*$ represents capacity output for this firm given the quasi-fixed input $K_0$, because it is the potential level of output that can be generated when a firm is equipped with a quasi-fixed input $K_0$ and when there is no restriction on the availability of variable input $L$. Therefore, C is a full capacity point for firm A. Following the above concept of gross and net capacity utilization, technical efficiency is given by $TE = \frac{Q_0}{Q_0^*} = \frac{L_0A}{L_0B}$, gross capacity utilization rate is $CU_G = \frac{Q_0}{Q_0^*} = \frac{L_0A}{L_0C}$, and net capacity utilization rate is $CU_N = \frac{Q_0^*}{Q_0} = \frac{L_0B}{L_0C}$. In general, gross capacity utilization measure is lower than net capacity utilization measure.

Economic based capacity utilization depicts the potential output measures within an optimization framework, giving the state of technology, quantity of quasi-fixed inputs and variable inputs and exogenous prices of inputs. Morrison (1985) summarized the fundamental idea of economic based measures in that firms face short-run constraints such as the stock of capital and, as a result, short-run equilibrium output might differ from that of a long-run steady-state equilibrium because of the short-run capital constraint. The economic based measure of capacity utilization can be classified into either primal or dual approaches. The primal approach to capacity utilization focuses on a comparison of the observed output ($Q$) and the capacity output ($Q^*$). This structure was first proposed by Cassel (1937) and Hickman (1964). Cassel defined the capacity output, $Q^*$, as the
minimum point of short-run average total cost (SRTAC) curve. For example, points A and B in Figure 4.4 provide capacity output points. Considering a firm’s technology is characterized by non-constant return to scale, Klein (1960) and Frieman (1963) advocated for another concept of capacity output. Klein defined capacity output as the point of tangency between long-run average cost (LRTAC) curve and short-run average total cost curve (SRTAC) as in point B’ in Figure 4.4. Note, when the firm operates under constant returns to scale the two measures are equivalent. Knowledge of these cost curves can determine why the firm’s capacity output Q* differs from observed output Q, thus, explicitly determines an endogenous measure of capacity utilization, \( CU = \frac{Q}{Q^*} \).

To be more specific, the tangency point between SRTAC and LRTAC can be directly characterized and the capacity output can be derived using parametric methods. The resulting capacity utilization measure is an explicit function of the exogenous variables and the parameters of the cost function.

![Figure 4.4 Behavioral Based Capacity Utilization](image-url)
Mathematically, suppose the firm’s production function is given by:

\[ Q = f(L, K, t) \]  

(4.12)

where \( L \) and \( K \) represent the quantities of labour input (variable input) and capital stock (fixed input), respectively; and \( t \) is an index of disembodied technical change. Let \( w \) be the price per unit of labour input \( L \) and \( r \) be the price per unit of current capital stock \( K \).

In the long-run, both the conditional demands for \( L \) and \( K \) are dependent on quantity of output, and the long-run total cost is

\[ \text{LRTC} = w \times L(Q) + r \times K(Q) \]  

(4.13)

In the short-run, the firm cannot adjust capital stock. Thus, capital stock is independent of the quantity of output, while labour input is dependent on the quantity of output. Given a variable cost function of \( G(Q, K, P_L, t) \), the firm’s short run average total cost is given by

\[ \text{SRATC} = \frac{G(Q, K, P_L, t)}{Q} + \frac{r \times K}{Q} = \frac{w \times L(Q, K, t)}{Q} + \frac{r \times K}{Q} \]  

(4.14)

If we denote \( Q^*_M \) as the capacity output determined at the minimum point of SRATC curve defined by Cassel (1937), then we have

\[ \frac{\partial \text{SRATC}}{\partial Q^*_M} = \frac{1}{Q^*_M} \frac{\partial G}{\partial Q^*_M} - \frac{G}{Q^*_M^2} - \frac{r \times K}{Q^*_M^2} = 0 \]  

(4.15)

Consider an alternative measure of capacity output advocated by Klein (1960). Denote \( Q^*_T \) as the capacity output that corresponds to the level of output at the tangency point between the SRATC curve and LRATC curve. In other words, we can calculate \( Q^*_T \)
by imposing the condition that SRMC equals to LRMC. By definition, in the short-run only variable cost are freely adjustable, so

\[
\text{SRMC} = \frac{\partial G(\bar{Q}, K, P_L, t)}{\partial Q_T} + 0 = \frac{\partial G}{\partial Q_T} 
\] (4.16)

The LRMC can be specified as

\[
\text{LRMC} = \frac{\partial G(\bar{Q}, K, P_L, t)}{\partial Q_T} + \frac{\partial r + K}{\partial Q_T} = \frac{\partial G}{\partial Q_T} + \frac{\partial G}{\partial K} \frac{\partial K}{\partial Q_T} + r \frac{\partial K}{\partial Q_T} 
\] (4.17)

Equating 4.16 and 4.17, we can obtains

\[-\frac{\partial G}{\partial K} = r \] (4.18)

Since \(-\frac{\partial G}{\partial K}\) can be interpreted as the shadow value of capital stock (denote as \(Z_r\)), which implies the firm is in long-run equilibrium if the shadow value of capital stock \(Z_r\) is equal to the price of capital \(r\).

A dual cost minimization approach to capacity and capacity utilization measurement has also been used in the literature (Morrison, 1985). As opposed to the primal cost minimization approach, dual cost minimization approach focuses on a comparison of firm’s actual cost to its long-run optimal cost. Graphically, suppose a firm operates at constant return to scale. The long-run average cost curve (LRAC) is presented in Figure 4.5. Figure 4.5 shows that point \(A\) is the optimal production point for SRAC\(_0\) curve. The SRAC\(_0\) is determined by the capital stock level of \(K_0\), price of capital \(r\) and other exogenous variables. The output level \(Q^*\) is the optimal output corresponding to the minimum point of SRAC\(_0\) curve. Assume a firm experienced an unexpected increase in
demand of output, $Q'$ is larger than $Q^*$. This disequilibrium could be the result of a unit costs increase, which leads to the shadow value of capital stock $Z_r$ exceeding the rental price of capital stock $r$. Consequently, the corresponding short run average cost curve shift from SRAC$_0$ to SRAC$_{sh}$. In the long-term, the capital stock $K$ is allowed to adjust. Therefore, the SRAC$_{sh}$ curve will shift to the SRAC$_2$ curve where tangent to the LRAC curve. And the SRAC$_2$ curve is determined by a new capital stock level of $K_1$ and other exogenous variables. However, in the short run, the firm is not able to adjust its capital stock. Thus, capital stock $K$ will hold constant at $K_0$ and output will be adjusted by the exogenous variables except capital stock, such as price of output and price of labour. Given this basis, the dual cost approach of capacity utilization should measures the cost of being at point A and at point C. The ratio form of capacity utilization is expressed as $\frac{TCOST(Q')}{TCOST(Q^*)}$. Alternatively, the dual cost approach of capacity utilization can be also defined as a comparison of shadow value of capital and actual price of capital. Here, the comparison of cost is measured between point B and point C, and it is expressed as $\frac{SHCOST(Q')}{TCOST(Q')}$. 
In the next section, I provide a dual profit maximization approach to determine capacity and capacity utilization.

4.5.2.2 Dual Profit Maximization Approach

Suppose a firm with production technology $T(Q, K, L)$. $p$ stands for the price of output, $w$ is price of labour and $r$ is \textit{ex ante} quasi-fixed input rental price. Therefore, the firm maximum profit function is expressed as

$$
\max \pi = pQ - w'L - rK \quad s.t. \quad T(Q, L, K) \leq 0 \quad (4.19)
$$

The \textit{ex ante} problem facing the firm is to choose the values of $Q$, $K$ and $L$ that maximize the expected profit. The results of the optimization problem is a profit function of the form:
\[ \pi^*(\bar{p}, \bar{w}, \bar{r}) = \pi^*(\bar{p}, \bar{w}, \bar{r}, K(\bar{p}, \bar{w}, \bar{r})) \]  
(4.20)

where \( \sim \) represents expected prices. By invoking Hotelling Lemma, the economic capacity output can be given by

\[ Q^*(\bar{p}, \bar{w}, \bar{r}) = \frac{\partial \pi^*(\bar{p}, \bar{w}, \bar{r})}{\partial \bar{p}} \]  
(4.21)

where \( Q^*(\bar{p}, \bar{w}, \bar{r}) \) satisfies the definition of economic capacity output since \( Q^*(\bar{p}, \bar{w}, \bar{r}) \) gives the level of output the firm expects to produce at equilibrium.

The ex post profit maximization problem facing the firm is to maximize profit by choosing \( Q \) and \( L \) given quasi-fixed input, \( K(\bar{p}, \bar{w}, \bar{r}) \), and the resulting profit function is given by:

\[ \pi = \pi(p, w, K(\bar{p}, \bar{w}, \bar{r})) \]  
(4.22)

The ex post problem involves profit maximization subject to the constraint that the quasi-fixed input is chosen on the basis of expected prices, and is now pre-determined. Thus, the ex post profit maximizing output is given by:

\[ Q(p, w, K(\bar{p}, \bar{w}, \bar{r})) = \frac{\partial \pi(p, w, K(\bar{p}, \bar{w}, \bar{r}))}{\partial p} \]  
(4.23)

Capacity utilization can, then, be measured as:

\[ CU^\pi = \frac{Q(p, w, K(\bar{p}, \bar{w}, \bar{r}))}{Q^*(\bar{p}, \bar{w}, \bar{r})} \]  
(4.24)

Next, I provide a simple stimulation results based on profit maximization. Assume a Cobb-Douglas production function of the form \( Q = L^aK^b \), and decreasing returns to scale \( a+b<1 \ (f'>0; f'' <0) \); the ex ante profit maximization problem is

\[ \max \pi = \bar{p}Q - \bar{w}'L - \bar{r}K \ \ s.t. \ Q = L^aK^b, \ a+b<1 \]  
(4.25)
Solving for the first order condition yields the following input demand function and output supply function:

\[
L^* = \bar{p}^{1-a-b} \left( \frac{w}{\bar{a}} \right)^{\frac{1-b}{a+b-1}} \left( \frac{\bar{r}}{b} \right)^{\frac{b}{a+b-1}} \tag{4.26}
\]

\[
K^* = \bar{p}^{1-a-b} \left( \frac{w}{\bar{a}} \right)^{\frac{a}{a+b-1}} \left( \frac{\bar{r}}{b} \right)^{\frac{1-a}{a+b-1}} \tag{4.27}
\]

\[
Q^* = \bar{p}^{\frac{a+b}{1-a-b}} \left( \frac{w}{\bar{a}} \right)^{\frac{a}{a+b-1}} \left( \frac{\bar{r}}{b} \right)^{\frac{b}{a+b-1}} \tag{4.28}
\]

The \textit{ex post} constrained profit maximization problem is given by

\[
\text{Max } \pi = PQ - w'L - rK \text{ s. t. } Q = L^a K^b, \ a+b<1, K^* = K(\bar{p}, \bar{w}, \bar{r}) \tag{4.29}
\]

Resulting in the following condition of input demand function and output supply function

\[
L^{s*} = \left( \frac{w}{apK(\bar{p}, \bar{w}, \bar{r})^b} \right)^{\frac{1}{a-1}} \tag{4.30}
\]

\[
Q^{s*} = \left( \frac{w}{apK(\bar{p}, \bar{w}, \bar{r})^b} \right)^{\frac{a}{a-1}} K(\bar{p}, \bar{w}, \bar{r})^b \tag{4.31}
\]

\[
CU = \frac{Q^{s*}}{Q^*} = \left( \frac{w}{apK(\bar{p}, \bar{w}, \bar{r})^b} \right)^{\frac{a}{a-1}} K(\bar{p}, \bar{w}, \bar{r})^b \tag{4.32}
\]

Using the properties of profit function and output supply function (Varian 1992), a number of hypotheses regarding capacity utilization can be developed. For example, an increase in the price of output is expected to have a positive effect on output supply. So an increase in output leading to an increase in capacity utilization, \( \frac{\partial CU^\pi}{\partial p} > 0 \). Similarly, if the price of labour increases, the quantity demanded of labour will decrease, and the
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output supply function will shift to the left, leading to a decline in capacity utilization, \( \frac{\partial CU^\pi}{\partial w} < 0 \). Thus, in periods where raw material or labour cost is higher, we would expect capacity utilization to decrease. For a firm that exports its products to a foreign market, with revenue denominated in the foreign currency\(^{15} \), if the foreign currency appreciates in real terms, the domestic firm may gain a competitive advantage and hence the quantity supplied of the domestic production to the foreign market will increase, that is, \( \frac{\partial CU^\pi}{\partial e} > 0 \).

A similar line of reasoning can be followed for input markets if the domestic firm imports its inputs from foreign countries with the opposite effect of the change in exchange rate for the output market.

\(^{15}\) revenue = \( e p^* Q \), where \( e \) denotes the number of currency units per unit of the foreign currency, \( p^* \) is the product price denominated in the foreign currency.
A numerical simulation example can be used to show the capacity utilization change corresponding to changes in exogenous variables. First, I assume $\bar{p} = 2; \bar{w} = 1; \bar{r} = 1; \alpha = 0.4$ and $\beta = 0.4$. We can determine the *ex ante* optimal values of $Q^*$, $L^*$ and $K^*$ based on my previous assumptions. In the short-run, capital stock does not adjust, remaining at $K^*$. Then, we can change the exogenous variables such as price of output to see whether the capacity utilization will increase or decrease. Figure 4.6 shows the numerical results of the change in capacity utilization caused by the changes in wage rate and exchange rate. Figure 4.6 indicates that an increase in the output price and exchange
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rate\textsuperscript{16} leads to an increase in capacity utilization. However, an increase in the price of labour leads to a decrease in capacity utilization. The simulated results are consistent with the previous hypothesis.

4.5 Summary

The above discussion provides alternative measures of capacity and capacity utilizations. The comparison of these methods is beyond the scope of the present study. Considering lack of price information, the study is based on the technical based concept of capacity utilization. Technical based capacity utilization is useful indicator of an overall trend in capacity utilization changes. Nelson (1989) examined the U.S. privately owned electric utilities’ capacity utilization between 1961 and 1983. He showed the value of technical based capacity utilization is lower than the value of economic based capacity utilization, though there is a strong correlation between the two measures.

\textsuperscript{16}The exchange rate here is the number of currency units per unit of the foreign currency.
Chapter 5

Empirical Model

In this chapter, I first introduce the output orientated data envelopment analysis model under the assumption of variable returns to scale to construct production frontier and to estimate the technical efficiency. I then explain the estimation of pure technical efficiency, scale efficiency and capacity utilization using data envelopment analysis. Next I present the Malmquist productivity index and distance function, and provide the decomposition of the Malmquist productivity index into technology change, scale efficiency change, gross capacity utilization change and capacity utilization change.

5.1 Data Envelopment Analysis

Data envelopment analysis is a conventional mathematical programming approach used to construct a non-parametric piece-wise frontier over the observed data, allowing for measurement of the production unit’s productivity and efficiency. Data envelopment analysis was first proposed by Charnes, Cooper and Rhodes (CCR) (1978). CCR model built under the assumption of input orientation and constant return to scale. For this study I use a ratio form to explain the idea behind the CCR model as follows. For each province $i$, we would like to obtain the maximum ratio of all outputs over all inputs
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\[
\begin{align*}
\text{Max}_{\mu, \nu} \left( \frac{\mu q_i}{\nu x_i} \right) \\
\text{s.t.} \quad \left( \frac{\mu q_i}{\nu x_i} \right) \leq 1 & \quad i = 1, 2, \ldots, I; \\
\mu, \nu \geq 0
\end{align*}
\]  

(5.1)

where \( \mu \) is an \( M \times 1 \) vector of output weights and \( \nu \) is an \( N \times 1 \) vector of input weights. \( x_i \) is input for province \( I \), and \( q_i \) is output for province \( i \). This mathematical programming problem calculates the values of \( \mu \) and \( \nu \) to find the maximized level of efficiency for each province. But given that the objective of the mathematical program is to maximize a ratio rather than a scalar, the ratio is made of two unknown numbers. Thus, there are infinite solutions for the combinations of \( \mu \) and \( \nu \). To avoid the infinite solutions, Charnes, Cooper and Rhodes (1978) impose the constraints \( \nu x_i = 1 \) or \( \mu q_i = 1 \) in the mathematical programming problem. This change of model structure leads to a linear form and the model has a unique optimal solution for either \( \mu \) or \( \nu \). The model is called multiplier program, because \( \mu \) and \( \nu \) are output multipliers and input multipliers, respectively. With regards to the linear program, it has the features of duality, which allows the model to derive an equivalent envelopment form of this problem. Therefore, the output orientated CCR envelopment program is rewritten as follow:

\[
\begin{align*}
\text{Max}_{\theta, \lambda} \theta \\
\text{s.t.} \quad \theta q_{i,m} & \leq \sum_{i=1}^{I} \lambda_i Q \quad m = 1, 2, \ldots, M; \\
x_{i,n} & \geq \sum_{i=1}^{I} \lambda_i X \quad n = 1, 2, \ldots, N; \\
\lambda_i & \geq 0 \quad i = 1, 2, \ldots, I
\end{align*}
\]  

(5.2)

where \( \theta \) is a scalar reflecting the level of technical efficiency with value no greater than one. \( \lambda \) is a \( I \times 1 \) vector of constants representing the intensity variable for the \( i \)-th province. \( Q \) is the \( M \times 1 \) output matrix and \( X \) is an \( N \times I \) input matrix representing the production data for all firms. The objective of this program is to maximize the value of
efficiency, $\theta$, because the output orientation considers a maximal proportional expansion of the output vector by a given input vector. The first and second constraints mean the i-th province seeks to proportionally expand the output vector $q$, while still keeping the production input within the feasible input set (the usage of input for the i-th firm should no less than the optimal demand of target output). The radial expansion of the output vector produces a projected point ($\lambda X, \lambda Q$) on the production frontier.

The main limitation of basic CCR model is the assumption of constant returns to scale. This assumption is commonly relaxed in empirical studies. For example, Gervais et al. (2008) examine economies of scale in the Canadian food processing industry at provincial level. They find the evidence that most Canada provinces show a significant increase in returns to scale. Banker, Charnes and Cooper (BCC) (1984) modified the basic CCR model. They extend the model to allow for the assumption of variable returns to scale. The BCC envelopment model adds one more constraint to the existing linear program problem:

$$\sum_{i=1}^{I} \lambda_i = 1$$  \hspace{1cm} (5.3)

This convexity constraint envelope the data points more tightly than the CCR model. Part of technical inefficiency obtained from CCR model is caused by scale inefficiency. Thus, technical efficiency provided by the BBC model (note as pure technical efficiency) is greater than or equal to those obtained from the CCR model.

### 5.2 Estimation of Pure Technical Efficiency and Scale Efficiency

In DEA, technical efficiency can be decomposed into pure technical efficiency (PTE) and scale efficiency (SE). The pure technical efficiency is measured under the assumption of
variable returns to scale. In other words, it is a measure of technical efficiency without scale inefficiency and purely reflects the efficiency of transfer inputs to production outputs. The pure technical efficiency can be using 5.3 and 5.2, and can be expressed as:

\[
PTE = TE_{VRS} = \max_{\theta, \lambda} \theta \\
\text{s.t.} \quad \theta q_{i,m} \leq \sum_{i=1}^{I} \lambda_i Q \quad m = 1,2, ... M; \\
\quad x_{i,n} \geq \sum_{i=1}^{I} \lambda_i X \quad n = 1,2, ... N; \\
\quad \lambda_i \geq 0 \quad i = 1,2, ... I \\
\quad \sum_{i=1}^{I} \lambda_i = 1 
\]

The value of pure technical efficiency is greater than the overall technical efficiency when scale inefficiencies exist because the overall technical inefficiency is caused by both the inefficient transformation of inputs into outputs and not operating at the optimal scale. Therefore, the measurement of scale efficiency can be expressed as a ratio of the technical efficiency to pure technical efficiency, and it is written as:

\[
SE = \frac{TE}{PTE} = \frac{TE_{CRS}}{TE_{VRS}} 
\]

**5.2 Estimation of Net Capacity Utilization**

Based on Johansen (1968) technical based definition of capacity, Fare *et al.* (1994) developed an approach to measure capacity utilization using data envelopment analysis. Fare *et al.* separate the input vector in BCC model into a sub-vector of variable inputs and a sub-vector of fixed inputs, whereas the available amount of variable inputs are not limited. The modified mathematical programming problem is expressed as:
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\[
\begin{align*}
\text{Max}_{\theta, \lambda, \delta} & \theta \\
\text{s. t.} & \quad \theta q_{i,m} \leq \sum_{i=1}^{I} \lambda_i Q \quad m = 1, 2, \ldots M; \\
& \quad x_{i,f} \geq \sum_{i=1}^{I} \lambda_i X_f \quad f = 1, 2, \ldots F; \\
& \quad \delta x_{i,v} = \sum_{i=1}^{I} \lambda_i X_v \quad v = 1, 2, \ldots V; \\
& \quad \sum_{i=1}^{I} \lambda_i = 1 \\
& \quad \lambda_i \geq 0 \\
& \quad \delta_i \geq 0
\end{align*}
\] (5.6)

where \(x_f\) and \(x_v\) represent the vector of fixed inputs and vector of variable inputs for each province, respectively. A new parameter \(\delta\) is assigned to variable inputs and captures the input utilization rate. In other words, if a province wanted to increase its aggregate output, its firms should increase utilization of its fixed input as well as increase the efficient use of variable inputs. \(\theta\) denotes gross capacity utilization rate, which measures the gap between actual output and capacity output. When pure technical inefficiency is present, then part of the output gap is caused by inefficient utilization of variable inputs. Therefore, the estimation of capacity utilization will be downward biased. To avoid this problem, we should eliminate the inefficiency caused by variable inputs, and the function is expressed as:

\[
CU_N = \frac{CU_G}{TEVRS} = \frac{\theta}{TEVRS}
\] (5.7)

where \(CU_N\) is net capacity utilization rate. \(CU_G\) is gross capacity utilization\(^{17}\), it measures the pure technical efficiency relative to full capacity.

\(^{17}\) The detail discussion of gross capacity utilization and net capacity utilization can be found in section 4.5.1.
5.4 Malmquist Productivity Index

Caves et al. (1982) first introduced the Malmquist productivity index. The Malmquist productivity index is constructed by measuring the radial distance functions of the observed output and input in two time periods with a given reference technology. A distance function can be categorized into either output or input orientations, thus the Malmquist productivity index can be output and input orientations. In this study, I use an output distance function to construct the Malmquist productivity index because an output distance function is a radial expansion of the output given set of inputs used. And in this study, capital stock is a fixed input that cannot be adjusted in short-run.

The Malmquist productivity describes the productivity change over two time periods and a result there are two different reference technologies. In order to avoid the problem of arbitrary choice of different reference technologies based on different periods, Fare et al. (1995) use a geometric average of the two indices to specify the Malmquist productivity index. The output-orientated Malmquist productivity index is expressed as:

\[
M_{0}^{t,t+1}(x^t, q^t, x^{t+1}, q^{t+1}) = \left( \frac{D_{0}^{t}(x^{t+1}, q^{t+1})}{D_{0}^{t}(x^{t}, q^{t})} \times \frac{D_{0}^{t+1}(x^{t+1}, q^{t+1})}{D_{0}^{t+1}(x^{t}, q^{t})} \right)^{1/2}
\]

(5.8)

If the value of the Malmquist productivity index is equal to one, it means productivity has not changed over the given periods. If the value is greater than one, it indicates an improvement in productivity by \((M_{0}^{t,t+1} - 1) \times 100\%\), vice versa.
5.4.1 The Decomposition of the Malmquist Productivity Index

The output-orientated Malmquist productivity index can be decomposed into two components:

\[
M_{0,t+1}^{t,t+1}(x^t, q^t, x^{t+1}, q^{t+1}) = \frac{D_0^{t+1}(x^{t+1}, q^{t+1})}{D_0^t(x^t, q^t)} \times \sqrt{\frac{D_0^t(x^t, q^t)}{D_0^{t+1}(x^{t+1}, q^{t+1})}} = \frac{D_0^t(x^t, q^t)}{D_0^{t+1}(x^{t+1}, q^{t+1})}
\]

where the first component is a ratio of two distance functions measuring the change in technical efficiency from time period t to time period t+1. The second component captures technical change over time period.

Assuming a variable returns to scale technology, Grifell-Tatje and Lovell (1998) proposed a Generalized Malmquist Index that can account for the effect of a change in scale efficiency on productivity. The scale efficiency can be derived from technical efficiency under variable returns to scale divided by technical efficiency under constant return to scale. Therefore, the scale efficiency change can be conceptualized as follows:

\[
M_{0,t+1}^{t,t+1}(x^t, q^t, x^{t+1}, q^{t+1}) = \frac{D_0^{t+1}(x^{t+1}, q^{t+1})}{D_0^t(x^t, q^t)} \times \sqrt{\frac{D_0^t(x^t, q^t)}{D_0^{t+1}(x^{t+1}, q^{t+1})}} = \frac{D_0^t(x^t, q^t)}{D_0^{t+1}(x^{t+1}, q^{t+1})}
\]

The change in technical efficiency again can be decomposed into two components: the change in pure technical efficiency and the change in scale efficiency.

Borger and Kerstens (2000) extend the Malmquist productivity index to allow for changes in plant capacity utilization. They build the model based on the primal approach...
CHAPTER 5. EMPIRICAL MODEL

suggested by Fare et al. (1994). As noted by Borger and Kerstens (2000), pure technical efficiency can be calculated as:

\[ D_{0,vrs}^t(x^t, q^t) = \frac{CUU_t^x}{CUU_N} = \frac{D_{0,vrs}(x^t, q^t)}{CUU_N(x^t, x^t, q^t)} \]  

(5.11)

Substituting equation (5.11) into equation (5.10), the corresponding expression for the Malmquist productivity index can be written as:

\[ M_{0,t+1}^{t}(x^t, q^t, x^{t+1}, q^{t+1}) = \sqrt{\frac{D_{0,vrs}(x^{t+1}, q^{t+1})}{D_{0,vrs}(x^t, q^t)} * \frac{D_{0,vrs}(x^{t+1}, q^{t+1})}{D_{0,vrs}(x^t, q^t)} * \frac{D_{0,vrs}(x^{t+1}, q^{t+1})}{D_{0,vrs}(x^t, q^t)} * \frac{D_{0,vrs}(x^{t+1}, q^{t+1})}{D_{0,vrs}(x^t, q^t)}} \]

(5.12)

The third component measures the change in gross capacity utilization from time period t to t+1. The fourth component captures the change in (net) capacity utilization from time period t+1 to t.

In sum, the Malmquist productivity index can be decomposed into four sources of productivity growth: technology change, scale efficiency change, gross capacity...
utilization change and capacity utilization change. If the value of each component is larger (or smaller) than one, it suggests an improvement (or deterioration), except for capacity utilization. For the value of capacity utilization change, a value larger (or smaller) than one, it suggest deterioration (or improvement).


Chapter 6

Data

6.1 Data

I use annual data from Statistics Canada over the period 1990 and 2012 at the provincial level. The data are collected through the Annual Survey of Manufactures and Logging (ASML) and the Fixed Capital Flows and Stocks program. The ASML is an annual survey for the Canadian manufacturing and logging industries. ASML covers detailed principal industrial statistics, as well as the commodities produced and consumed. Fixed Capital Flows and Stocks program comprises information for all business and government entities operating in Canada and it provides annual estimates of fixed capital stock information by perpetual inventory method (PIM). For this study, one aggregate output (i.e., value-added) and four aggregate inputs (energy, labour, materials and capital) are defined for our empirical model.

Manufacturing Value-added

Typically, manufacturer’s output can be classified into two categories: gross revenue and value-added. The OECD (2001) notes productivity measurement at an industry level should be based on value-added. Value-added measures the difference between the
industry’s revenue and its intermediate production cost. Manufacturing value-added is obtained from CANSIM Table 301-3003 and 301-3006. It is defined as the value of revenue from goods manufactured, taking into account the net change in goods-in-process and finished product inventories, minus the cost of materials and supplies, and the total cost of purchased energy, water utility and vehicle fuel, and the amount paid for custom work. The manufacturing value-added is in nominal terms and thus needs to be converted into real terms using price index. The industry product price (IPP) index in CANISM table 329-0038 is available starting 1992, but not available at the provincial level. In order to make the analysis more accurate, I use different price indexes for different provinces. Hence, I use the consumer price index (CPI) (CANISM table 329-0021). The CPI is available from 1914 to 2013 at the provincial level. I use the CPI food product group to be the output price index based on the year 2002.

**Energy**

Nominal energy costs are obtained from CANSIM Table 301-3003 and 301-3006. It consists of the expenses for purchases of energy (electricity, gasoline, fuel oil, diesel fuel, natural gas, coal, etc.), public water utilities used by the establishment, and vehicle fuel. The electric power selling price index (CANSIM Table 329-0073) for non-residential use is been categorized into two groups: electric power selling price over 5000kw and electric power selling price under 5000kw. I use the CPI for water, fuel and electricity group at provincial level to deflate energy expense based on the year 2002.
CHAPTER 6. DATA

Labour

I use total salaries and wages for both direct and indirect labour for labour cost. Total salaries and wages were obtained from CANSIM table 301-3003 and 301-3006 and include gross earnings of employees who are engaged in both manufacturing and non-manufacturing operations, excluding withdrawals of working owners and partners. The OECD (2008) suggests using the labour price index to deflate nominal labour cost. Labour price index is designed to measure changes in the hourly compensation of a fixed “basket of jobs”. Statistics Canada doesn’t have the labour price index. Kumar and Basu (2008) use the consumer price index (CPI) as deflator for labour cost in their study of India food manufacturing productivity. Sharpe et al. (2008) examine the labour productivity in Canada and use the CPI to deflate nominal wages. Considering Statistics Canada does not provide information a labour price index, I use CPI as the labour cost deflator in this study. Labour cost is deflated by an all-item CPI at the provincial level based on year 2002, where the all-item CPI covers all the goods and services intended to represent a family’s consumption level.

Materials

Materials and supplies cost was obtained from CANSIM Table 301-3003 and 301-3006. It sums the cost of materials, supplies and components used in manufacturing and related operations, the purchase of single-use containers and shipping and packaging material, the execution of subcontracts, and repair and maintenance. I use the total farm product
price index (FPPI) as a deflator to covert materials and supplies cost into real term. The majority materials and supplies cost is primary agricultural products purchased from farmers and FPPI measures the change through time in prices received by farmers from the sale of agricultural products. The FPPI comprises prices for total crops, total livestock and animal products. FPPI is obtained from CANSIM Table 002-0069 at a provincial level based on the year 2002.

**Capital**

Fixed Capital Flows and Stocks program provides information for capital stock by NAICS. CANSIM table 031-0002 includes fixed non-residential capital stock in the food processing industry from 1990-2012. The non-residential capital stock comprised information for four asset groups: building construction, engineering construction, machinery, and equipment and intellectual property products. It is based on the perpetual inventory method to calculate the Geometric (infinite) end-year net capital stock. The non-residential capital stock is, however, only available at national level and for some provinces (Quebec, Ontario, Alberta and British Columbia). In order to generate capital stock for each province, I use the method suggest by Baldwin *et al.* (2013). Baldwin *et al.* suggest energy cost is proportional to capital stock. Thus, I allocate the national aggregate capital stock in the food processing industry to each province base on their share of the total energy cost\(^\text{18}\). I also run the correlation test between the estimated capital stock and capital stock obtained from CANISM table 031-0002 for the four

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\(^{18}\) Each province’s share of total energy cost is calculated by using each province’s energy cost divide by national energy cost.
provinces: Quebec, Ontario, Alberta and British Columbia. The results are presented in Table 6.1. Table 6.1 shows that the estimated capital stock is highly correlated with the number obtained from Statistics Canada. The price index for the non-residential capital stock is obtained from CANISM table 031-0002 base on year 2002.

<table>
<thead>
<tr>
<th></th>
<th>Capital Stock Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quebec</td>
<td>0.9263</td>
</tr>
<tr>
<td>Ontario</td>
<td>0.9638</td>
</tr>
<tr>
<td>Alberta</td>
<td>0.9603</td>
</tr>
<tr>
<td>British Columbia</td>
<td>0.8217</td>
</tr>
</tbody>
</table>

6.1.1 4-Digit NAICS Food Manufacturing Sectors

Considering the differences in the economic structures of food manufacturing industries across provinces and heterogeneity in technology across various food manufacturing subsectors, we also estimate productivity at a subsector level. For example, Atlantic Provinces are dominated by seafood production preparation and packaging industry, and the Prairies Provinces are dominant by meat processing and grain milling industry. Hence, I further evaluate the productivity performance at five 4-digit NAICS food processing subsectors at provincial level: animal food manufacturing (3111); grain and oilseed milling manufacturing (3112); dairy product manufacturing (3115); meat product manufacturing (3116) and seafood product preparation and packaging manufacturing (3117). The reason for choosing these five food processing subsectors is based on data availability. The five subsectors have sufficient data for more than four provinces.
CHAPTER 6. DATA

Specifically, there are four production inputs included in the empirical model. Hence, we need at least four provinces to construct the production frontier. With regards to the choice of provinces, I eliminate the provinces with less than 80% of data between 1990 and 2012.
Chapter 7

Results and Discussion

In this Chapter, I first discuss the descriptive statistics of aggregate national and provincial food processing sector’s output and inputs, as well as labour productivity. Then, I present the average level of capacity utilization, pure technical efficiency and scale efficiency for each province in three different periods 1990-1999, 2000-2007 and 2008-2012, which are characterized by changes in the global economic condition. Next, I present the average multifactor productivity growth for each province in the pre- and post-2000 periods. I also decompose the productivity change into technical change, scale efficiency change, gross capacity utilization change and capacity utilization change. Finally, I provide a comparison of productivity performance for five selected 4-digit NAICS food processing subsectors at provincial level, included animal food, grain and oilseed milling, dairy product, meat product and seafood product preparation industries.

7.1 Descriptive Statistics

Figure 7.1 provides the average market distribution of the food processing industry over the period 1990 to 2012 for each province. The figure indicates Ontario is

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19 Labour productivity is measured as a ratio of value-added and the number of workers.
the largest food processing province in Canada, with almost half of the total national value-added. Quebec also contributes a considerable share with approximately 22% of the national total. Ontario and Quebec play a major role in the Canadian food processing business, thus, these two provinces’ productivity performance is one of the key determinants of the Canadian food processing industry’s competitiveness in global markets. Alberta and British Columbia account for 9% and 8% share of the national value-added, respectively. The rest of the provinces market share are: 4% for Manitoba, 2% for Saskatchewan, 3% for New Brunswick, 3% for Nova Scotia, 2 % for Newfoundland and 1% for Prince Edward Island.

Figure 7.1 Average market distribution of the food processing business by province, 1990-2012

Figure 7.2 and 7.3 illustrate yearly changes in industry aggregate output and production inputs for Canadian food processing over 1990-2000 and 2000-2012,
respectively. The overall trend for value-added was upward in the pre-2000 period, stimulated by an increasing global demand for Canadian products. More specifically, in 1990 Canada signed a Free Trade Agreement (FTA) with the U.S., which is the largest food trade partner with Canada. The FTA lowered all agricultural tariffs, which improved the price competitiveness of Canadian processed food. At the same time, the Canadian dollar depreciated relative to the U.S. dollar, which further strengthened the price competitiveness of Canadian goods. Since 2000, tariffs have remained unchanged, the U.S. economy went into a recession, and the Canadian dollar start to appreciate. These trade environment changes led to a decline in global demand for Canadian processed food and lower domestic real value-added. In the pre-2000 period the change in value-added and the change in labour costs moved in the same direction. However, after 2000 labour costs no longer followed the change in the industry’s value-added. One possible explanation for this phenomenon might be that the cost of other production inputs increased faster than output increased, which in turn led to a lower rate of value-added growth.

In terms of capital stock the percentage change for most years was small at approximately 1-2%. The increasing demand for Canadian processed food and depreciation in the Canadian dollar before 2000 did not attract considerable investment in capital stock (e.g., machinery) by domestic food processors. Lafrance and Schembri (2000) hypothesized a depreciated real exchange rate may reduce producers’ incentive to make productivity-enhancing investments, as lower exchange rates may shelter domestic producers from global competition. After 2000, capital stock saw comparatively more fluctuations than during the pre-2000 period, which might be explained by Canadian food
processors importing most of their high-end technologies and machines from the U.S. (the appreciated value of Canadian dollar increased the domestic firm’s buying power). On the other hand, reduced demand for Canadian processed food could lead to a decline in firm’s revenue, and thus, a firm has less resources to acquire new technology or capital.

Even energy costs were more volatile than materials costs, the overall trend of both costs was upward. Oil is an important element in processing of food products and, as a result, one possible reason for the rise in energy cost could be changes in world oil prices. In 1999, the Organization of Petroleum Exporting Countries (OPEC) took coordinated action to control world oil prices in an attempt to prevent the Asian financial crisis, the result of which was a higher world oil price (Natural Resources Canada, 2010). In early 2000s, development in China and other emerging economies further boosted the demand of oil. Then in 2008, the world financial crisis strongly impacted the price of oil (Natural Resources Canada, 2010). All of these events affected the stability of energy prices. In contrast to the volatile increase in energy prices, the cost of materials experienced a steady increase over the last two decades. One potential reason for the rise in the cost of materials is the simultaneous rise in the price of raw agricultural commodities: in Canada, 38% of primary agricultural production was distributed to the food processing sector in 2010 (AAFC, 2015). Increases in the price of raw materials could have also been induced by: bad weather conditions, an increasing world population, or the emergence of the biofuels industry (OECD, 2008). For example, in recent years the U.S. has increased the use of corn to produce corn ethanol, which may reduce corn availability and therefore increase its price.
Chapter 7. Results and Discussion

Figure 7.2 Canadian food processing industry aggregate output and input changes between 1990 and 2012

Figure 7.2 Canadian food processing industry aggregate output and input changes between 1990 and 2012
Figure 7.3 Canadian food processing industry aggregate output and input changes between 2000 and 2012
CHAPTER 7. RESULTS AND DISCUSSION

Table 7.1 Each province food processing sector’s real value-added

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Newfoundland</td>
<td>408,427,561</td>
<td>317,431,125 (22%)</td>
<td>320,387,878 (0.9%)</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>134,364,417</td>
<td>302,455,032 (125%)</td>
<td>165,474,964 (-45%)</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>582,182,151</td>
<td>675,922,423 (16%)</td>
<td>401,024,566 (-41%)</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>589,133,819</td>
<td>713,502,651 (21%)</td>
<td>494,160,431 (-31%)</td>
</tr>
<tr>
<td>Quebec</td>
<td>4,538,035,885</td>
<td>4,656,317,938 (2.6%)</td>
<td>4,568,330,821 (-1.8%)</td>
</tr>
<tr>
<td>Ontario</td>
<td>8,297,901,425</td>
<td>9,704,278,440 (17%)</td>
<td>7,924,148,484 (-18%)</td>
</tr>
<tr>
<td>Manitoba</td>
<td>651,535,031</td>
<td>912,764,957 (40%)</td>
<td>1,241,082,554 (36%)</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>335,303,398</td>
<td>653,835,789 (94%)</td>
<td>713,502,681 (9%)</td>
</tr>
<tr>
<td>Alberta</td>
<td>1,089,798,534</td>
<td>2,237,740,541 (105%)</td>
<td>2,096,251,759 (-6%)</td>
</tr>
<tr>
<td>British Columbia</td>
<td>1,490,459,770</td>
<td>1,859,876,201 (25%)</td>
<td>1,882,256,410 (1%)</td>
</tr>
</tbody>
</table>

Canada        | 18,117,141,996 | 22,034,125,097 (22%) | 19,806,620,553 (-10%) |

Note: The number in bracket are percentage change in real value-added from 1990 to 2000 and 2000 to 2012, respectively.

Table 7.1 shows the real value-added by province for the years 1990, 2000 and 2012. Table 7.1 clearly indicates most provinces faced a growth in output from 1990 to 2000, except Newfoundland. Before 2000, Prince Edward Island, Saskatchewan and Alberta experienced the largest improvement, with approximately 100% growth in total real value-added. Meanwhile, Nova Scotia, New Brunswick, Ontario and British
Columbia also realized considerable growth in real value-added. Newfoundland is the only province that has experienced a decline in value-added with an approximately 22% drop. In the 1990s, Newfoundland experienced a significant structural changes, marked by a decline in groundfish processing and a switch into the shellfish and lumber industries (Economics and Statistics Branch, 2003).

Since 2000, the trend in output growth is reversed for most provinces. Prince Edward Island, Nova Scotia, New Brunswick and Ontario were all experiencing a drop in their value-added. Particularly Ontario, the largest food processing province, witnessed a considerable drop in its value-added by approximately 18%, while Nova Scotia and New Brunswick also generated much less value-added than their 1990 level. Even though most provinces in Canada went through a reduction in their output in the post-2000 period, Manitoba, Saskatchewan and British Columbia still kept an upward trend in their output production. In particular, Manitoba and Saskatchewan food processing sectors’ real value-added in 2012 was almost twice as much as it was in 1990. This considerable increase in the Prairie provinces may indicate the increasing importance of the food processing sector in those provinces, finding consistent with Sparling and LeGrow’s (2014) observation that many multi-national food processing plants have opened in Manitoba and Saskatchewan.
Figure 7.4 Average distribution of production input by province, 1990-2012

Figure 7.4 shows the average distribution of the four production inputs: materials cost, labour cost, capital cost and energy cost by province over 1990-2012. Material cost is the food processing sector’s largest cost, accounting 65% of total production cost on average. Thus, an increase in the price of materials may have a considerable effect on food processors’ profit and competitiveness. The next largest expense is capital, followed by labour and energy. It is also interesting that the distribution of production inputs varies across provinces. Manitoba, Alberta, Saskatchewan and British Columbia spent more than 66% of their total cost on materials. The average share of material expense for Ontario is approximately 64% and is 63.4% for Quebec. Newfoundland spent the least on materials. For Alberta, Saskatchewan and British Columbia, the share of capital cost is
smaller than other provinces. Prince Edward Island has highest share of capital stock with approximately 25.8% of the total cost, whereas Ontario’s capital cost accounts for average 20.4%. The cost of labour presents a different picture: Prince Edward Island, Saskatchewan and Alberta have lower share of labour cost with 9.32%, 8.92% and 8.41%, respectively, while in Ontario and Quebec labour cost accounts for approximately 13%. There is not much difference in energy cost share across provinces with every province spending approximately 2% of their total production cost on energy. The variation in distribution of production inputs can possibly be explained by the difference in industrial structures across provinces. For example, the Atlantic provinces are more oriented towards seafood processing and packaging, whereas the Prairie provinces are dominated by grain milling and meat processing. The OECD (2001) argues measurements of productivity should be made at the industry level due to the possibility for heterogeneous technologies across industries. The OECD (2001, p.8) defines an industry as “a group of establishments engaged in the same type of productive activity.” Thus, provinces characterized by different food industries may exhibit different production technologies.
Figure 7.5 Food processing sector’s labour productivity by province, 1990-2012
CHAPTER 7. RESULTS AND DISCUSSION

Figure 7.5 presents labour productivity in the food processing industry by province from 1990 to 2012, where labour productivity has been divided into three time periods. Ontario has the highest labour productivity with an average of $119,000 value-added per person over the entire study period; however, Ontario experienced a considerable decline in labour productivity after 2000. Each employee generated $127,000 value added between 1990 and 2000, which decreased to $111,000 between 2001 and 2012. Newfoundland, Prince Edward Island, Nova Scotia and New Brunswick have a similar trend despite lower levels of labour productivity in these four provinces. Moreover, their labour productivity dropped by more than 25% over last two decades. In addition, we observe that Prince Edward Island, Nova Scotia and New Brunswick have a close labour productivity during the entire timeframe, with an average of $55,000 per person. In contrast, labour productivity in Manitoba and Saskatchewan realized exceptional growth, achieving respective increases of 22% and 8% between 1990-2000 and 2001-2012. No considerable change in labour productivity occurred for Quebec, Alberta or British Columbia over the two periods and overall, average value-added per person is trending downwards Quebec and British Columbia, but upwards for Alberta.

To sum, even though Ontario has faced a considerable drop in labour productivity since 2000, it still maintains the highest provincial level. Labour productivity continues to grow in Manitoba, Saskatchewan and Alberta, gradually approaching the standard set in Ontario.

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Labour productivity measures the efficiency of each employee to generate the total value or added value. In this paper, I measure labour productivity as the ratio of value-added to the number of employees.
7.2 Capacity Utilization, Pure Technical Efficiency and Scale Efficiency

Table 7.2 presents the estimated capacity utilization for each province. The results are summarized into three time periods: 1990-1999, 2000-2007 and 2008-2012. The reason for dividing the entire study period into these three time periods is based on the changes in the business environment. For example, in 1990, U.S. and Canada signed a free trade agreement that promotes international trade between U.S. and Canada. Meanwhile, over 1990-1999, the U.S. economy experienced robust growth and the Canadian dollar depreciated in value leading to lower competitive pressure. Since 2000, the tariff on manufacturing products between the U.S. and Canada has remained unchanged and the Canadian dollar began to appreciate relative to the U.S. dollar. In addition, the 9/11 terrorist attack has increased trade cost at the borders between Canada and the U.S., which also led to a reduction in trade volume. The Canada economy has also seen a structural transformation from a manufacturing based industry to a resourced based industry. Since 2007, the world faced a serious financial crisis, including the U.S., during which the U.S. dollar kept depreciated in value with the Canada-U.S. exchange rate reaching parity in 2012.

To construct the reference the production frontier the DEA uses output and input data for all provinces. Thus, at least one province should be located on the production frontier (i.e. be a reference province), meaning that the reference province’s value of pure technical efficiency, scale efficiency, or capacity utilization is equal to 100%. First I report the results for capacity utilization rate. Based on the definition and explanation of technical based capacity utilization in Chapter 4 and 5. We know if the capacity utilization equals to 100%, it means the province has no potential for greater production
with the existing fixed input. If the capacity utilization is less than 100%, it means capacity is under-utilized and the province has potential for greater production with the existing fixed input. Table 7.2 presents average level of capacity utilization by province at three time periods. The results show that Ontario and British Columbia have higher capacity utilization rate than other provinces, implying capital stock in these two provinces has been fully utilized relative to other provinces.

Table 7.2 Average level of capacity utilization by province in 1990-1999, 2000-2007 and 2008-2012

<table>
<thead>
<tr>
<th>Regions</th>
<th>Province</th>
<th>Capacity Utilization (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic</td>
<td>Newfoundland</td>
<td>98.2</td>
</tr>
<tr>
<td></td>
<td>Prince Edward Island</td>
<td>86.2</td>
</tr>
<tr>
<td></td>
<td>Nova Scotia</td>
<td>91.1</td>
</tr>
<tr>
<td></td>
<td>New Brunswick</td>
<td>93.1</td>
</tr>
<tr>
<td>Prairie</td>
<td>Quebec</td>
<td>90.9</td>
</tr>
<tr>
<td></td>
<td>Ontario</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>Manitoba</td>
<td>81.5</td>
</tr>
<tr>
<td></td>
<td>Saskatchewan</td>
<td>83.3</td>
</tr>
<tr>
<td></td>
<td>Alberta</td>
<td>85.8</td>
</tr>
<tr>
<td></td>
<td>British Columbia</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Notes: Detail information about each province capacity utilization for each year can be found in Appendix A.

The Atlantic provinces experienced a considerable decline in capacity utilization over the study period, with the exception of Newfoundland where capacity utilization dropped from 98.2% in pre-2000 to 90.8% in 2000-2007 but recovered to 100% after
2008. In contrast, capacity utilization for Prince Edward Island and New Brunswick declined 10% after 2000. At the same time, capacity utilization for Nova Scotia is nearly unchanged between the pre-2000 and the 2000-2007 periods. Since 2008, Prince Edward Island, New Brunswick, and Nova Scotia decreased, with the decline in Prince Edward Island being quite considerable. The decline in Prince Edward Island’s capacity utilization could be the result of numerous Natural Organic Food Group (NOFG) pork plants closing combined the decline in French fry demand as a result of the global economic recession, particularly in the U.S. (Agrialliance, 2013).

Manitoba, Saskatchewan and Alberta experienced a decline in average capacity utilization in the 2000-2007 period. The difference between the Prairie and Atlantic regions is that the Prairie region’s capacity utilization saw a significant recovery after 2008. The average level of capacity utilization in Manitoba, Saskatchewan and Alberta was lower than in Ontario and British Columbia. One possible reason is the food processing plants in the Prairie Provinces are dominated by small plants; for example, 80% of food processors in Saskatchewan employ less than 20 people (Trimension Traning & Consulting Group Inc., 2012). The post-2000 decline in capacity utilization matches Baldwin et al. (2013), where the decline in most manufacturing sectors’ capacity utilization is explained by the increasing value of Canadian dollar and corresponding decrease in Canadian exports.

Table 7.3 presents the level of pure technical efficiency by province. The results indicate Ontario and British Columbia are technically efficient (with technical efficiency of 100%) over the entire period relative to other provinces. Newfoundland also experienced full technical efficiency before 2000, but dropped to 95.6% during the 2000-
CHAPTER 7. RESULTS AND DISCUSSION

2007 period before returning to 100% again after 2008. Unlike Newfoundland, Prince Edward Island experienced a dramatic decline in technical efficiency from 100% to 40.6%. Manitoba, Saskatchewan and Alberta had a higher improvement in technical efficiency, where all three Prairie provinces trending upwards over the past 20 years and their average technical efficiencies were close to 100% after 2008. Quebec shows a high level of technical efficiency, averaging around 95%. Overall, the Canadian food processing industry technical efficiency was on the rise, in particular after 2008.

Table 7.3 Average level of pure technical efficiency by province in 1990-1999, 2000-2007 and 2008-2012

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Newfoundland</td>
<td>100.0</td>
<td>95.6</td>
<td>100.0</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>100.0</td>
<td>87.6</td>
<td>40.6</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>88.7</td>
<td>97.0</td>
<td>87.2</td>
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<tr>
<td>New Brunswick</td>
<td>89.7</td>
<td>90.8</td>
<td>78.4</td>
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<tr>
<td>Quebec</td>
<td>94.8</td>
<td>92.3</td>
<td>96.4</td>
</tr>
<tr>
<td>Ontario</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Manitoba</td>
<td>76.4</td>
<td>98.5</td>
<td>100.0</td>
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<tr>
<td>Saskatchewan</td>
<td>80.7</td>
<td>92.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Alberta</td>
<td>87.2</td>
<td>91.4</td>
<td>99.4</td>
</tr>
<tr>
<td>British Columbia</td>
<td>99.4</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Notes: Detail information about each province pure technical efficiency for each year can be found in Appendix A.
Table 7.4 Average level of scale efficiency by province in 1990-1999, 2000-2007 and 2008-2012

<table>
<thead>
<tr>
<th>Province</th>
<th>Scale Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newfoundland</td>
<td>90.4</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>85.2</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>90.4</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>87.9</td>
</tr>
<tr>
<td>Quebec</td>
<td>99.5</td>
</tr>
<tr>
<td>Ontario</td>
<td>100.0</td>
</tr>
<tr>
<td>Manitoba</td>
<td>97.7</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>95.7</td>
</tr>
<tr>
<td>Alberta</td>
<td>98.9</td>
</tr>
<tr>
<td>British Columbia</td>
<td>97.6</td>
</tr>
</tbody>
</table>

Notes: Detail information about each province scale efficiency for each year can be found in Appendix A.

Table 7.4 presents the level of scale efficiency by province. Table 7.4 shows all provinces operate at an inefficient scale with scale efficiency dropping for most provinces in the post-2008 period consistent with Gervais et al. (2008). Gervais et al. find increasing returns to scale exist in most 4-digit NAICS sectors at the provincial level, except the dairy sector in Ontario and Quebec. The largest food processing provinces, Ontario and Quebec, witnessed a downward trend in scale efficiency. Scale efficiency in Quebec dropped from 99.5% before 2000 to 90.6% after 2008 and similarly Ontario’s scale efficiency changed from 100% in pre-2000 period to 91.4% after 2008. For the Atlantic region, scale efficiency did not change proportionate to the change in capacity.
utilization and technical efficiency. Over the entire period, most Atlantic provinces achieved an improvement in scale efficiency, except Prince Edward Island where scale efficiency decreased from 85.2% in the pre-2000 period to 70.2% in 2008-2012 period. Neither Manitoba, Saskatchewan, Alberta, nor British Columbia experienced considerable changes in scale efficiency, though their average scale efficiencies were above 95% over the study period.

7.3 Multifactor Productivity

One objective of the study is to evaluate food processing industry’s productivity performance by province, and to explore the contributions of the changes in capacity utilization, gross capacity utilization, scale efficiency and technology to the change in productivity. Hamit-Haggar (2009) suggest the decomposition of productivity change into its component parts could identify Canada’s productivity problems, which in turn would assist in the development of policies to reverse the situation and reduce the productivity gap between Canada and other industrial countries.

In this study, I estimate the multifactor productivity change for each province based on the concept of the Malmquist productivity index. The Malmquist productivity index describes the change in multifactor productivity from time t to time t+1 and is therefore a relative measure. Because it is estimated using data envelopment analysis (DEA), and DEA builds the upper bound of the production possible set by observed data, the degree of productivity changes for each province depicts their relative improvement or deterioration. A Malmquist productivity index equal to one implies no productivity change, an index greater than one implies an improvement in MFP, and an index less
CHAPTER 7. RESULTS AND DISCUSSION

than one implies deterioration in MFP. To ease interpretation, I use MFP change rates\textsuperscript{21} instead of the Malmquist productivity index itself to describe the degree of productivity changes over the period.

7.3.1 Malmquist Productivity Index

Table 7.5 Average multifactor productivity change\textsuperscript{22} by province (%), 1990-2012

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Newfoundland</td>
<td>-4.3</td>
<td>2.4</td>
<td>1.3</td>
<td>-0.9</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>6.7</td>
<td>-1.6</td>
<td>-1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>2.7</td>
<td>-4.9</td>
<td>-0.7</td>
<td>-0.5</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>1.8</td>
<td>0</td>
<td>-2.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Quebec</td>
<td>-1.3</td>
<td>0.3</td>
<td>-1.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>Ontario</td>
<td>1.1</td>
<td>-2.4</td>
<td>-1.9</td>
<td>-0.7</td>
</tr>
<tr>
<td>Manitoba</td>
<td>5.8</td>
<td>1.4</td>
<td>-2.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>10.1</td>
<td>-2.1</td>
<td>1.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Alberta</td>
<td>5.2</td>
<td>-0.2</td>
<td>-1.4</td>
<td>2</td>
</tr>
<tr>
<td>British Columbia</td>
<td>1.4</td>
<td>-2.1</td>
<td>1.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Notes: Detail information about each province’s multifactor productivity change for each year can be found in Appendix A.

\textsuperscript{21} The MFP change is calculated by subtracting from MPF and multiply by 100%. For example if the Malmquist productivity index is 1.1, the productivity change rate is (1.1-1)*100%≈10%.

\textsuperscript{22} The correlation test between multifactor productivity change and labour productivity change is 88.3%.
Table 7.5 indicates the average multifactor productivity change for each province from 1990 to 2012. I also divide the entire time frame into three different time periods, 1990-2000, 2000-2007 and 2007-2012. In the pre-2000 period, most provinces experienced a productivity improvement, with the exception of Newfoundland and Quebec. The rise in productivity may be caused by a number of factors such as the depreciation of the Canadian dollar before 2000 and the boost to the development of the food processing sector in the Prairie region provided by the removal of the Western Grain Transportation Act (Darcie Doan et al., 2003). Manitoba, Alberta and Saskatchewan’s food processing industry experienced an annual 5.8%, 5.2% and 10% growth in aggregate productivity. Prince Edward Island food processing industry’s productivity also saw a 6.5% annual growth rate, which may be attributed to the successful development of the potato processing business in 1990s (Arsenault, 2006).

Since 2000, appreciation the Canadian dollar and the unchanged tariff between Canada and U.S. created an unfavorable trade environment for Canadian food processors. Every province (except Newfoundland) experienced a decline in productivity after 2000. In the period 2000-2007, the multifactor productivity in Ontario has declined by an average of 2.4% per year. At the same time, Prince Edward Island, Nova Scotia, Saskatchewan and British Columbia have experienced considerable declines in productivity by 1.6%, 4.9%, 2.1% and 2.1% per year, respectively. But, Newfoundland and Manitoba had an increase in productivity by 2.4% and 1.4%, respectively. Since 2007, the world economy entered a recession, notably the U.S., Canada’s largest trade partner. The U.S. economy’s reduced the demand for Canadian merchandise, including processed food. Not surprisingly as a result, most provinces experienced a decline in
CHAPTER 7. RESULTS AND DISCUSSION

productivity over the period of 2007-2012. The productivity in Ontario and Quebec declined by an average of 1.6 and 1.9% annually. Over the same period, however, Newfoundland, Saskatchewan and British Columbia experienced a productivity growth, with an average of 1.3-1.5% per year. Newfoundland’s food processing industry exhibited a different scenario in the pre- and post-2000 compared with other provinces, which may be explained by the significant structural change that occurred with a marked decline in groundfish processing and consequential switch into shellfish and lumber industries in the 1990s (Economics and Statistics Branch, 2003). Although the fish processing industry accounts for a large portion of Newfoundland’s economic activity, the decline in groundfish availability and moratorium on the cod fish catch directly reduced Newfoundland’s food processing output. Since 1997, the sustainable increase in the quota of shellfish (e.g. crab, shrimp) led to a recovery in the Newfoundland seafood processing sector (Newfoundland Statistics Agency, 1999).

Over the entire study period, for Ontario and Quebec, the multifactor productivity dropped by an average of 0.7% and 0.8% per year, respectively. Similar productivity deterioration happened in Newfoundland and Nova Scotia, whereas British Columbia and New Brunswick realized a small increase productivity. At the same time, Prince Edward Island, Manitoba, Saskatchewan and Alberta exhibited considerable improvement in their multifactor productivities. For example, Saskatchewan’s productivity has increased by an average of 4.2% annually. Clearly, aggregate productivity growth over the entire 1990-2012 period varies across provinces.

The findings in this study regarding productivity changes across provinces is consistent with the structural changes across provinces. For example, Sparling and
LeGrow (2014) find Ontario and Quebec witnessed a large number of Canadian or multi-national food plants exit between 2006 and 2014. Plants with low productivity in Ontario and Quebec may have shut down or relocated to other jurisdictions. For example, plant investments and re-openings occurred in Alberta, Saskatchewan and Manitoba. This reopening of plants with modern processing technology has promoted productivity growth in the Prairie region. These trends are consistent with the results of Baldwin et al. (2013), who find the Canadian manufacturing industry as a whole experienced a growth slowdown post-2000.

In summary, as the most productive and largest food processing industries, Ontario and Quebec have seen a considerable decline in productivity over the last 20 years, declines which could merit a response in order to maintain their competitiveness in food processing. During the same period, Manitoba, Saskatchewan and Alberta saw considerable productivity growth. Even though the market share of these provinces is not as large as Ontario or Quebec, they do play an important role in enhancing Canada’s overall food processing productivity and competitiveness. For example, Manitoba’s food processing industry contributed approximately 28% of the total provincial manufacturing revenue in 2011, with most of this processed product destined for foreign markets (Ashton et al., 2014). Ashton et al., (2014) argue the price competitiveness of their products is driven by availability and low cost of raw materials, central location for exporting and transferring products, and access to quality water.
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7.3.2 Sources of Malmquist Productivity Growth

Grifell-Tatje and Lovell (1998) suggest a generalized Malmquist productivity index that can decompose MFP into technical change, scale efficiency change and gross capacity utilization change. Borger and Kerstens (2000) proposed a decomposition of the Malmquist productivity index that accounts for the contribution of capacity utilization changes. In this study, I combine the two approaches to decompose productivity into the change in technical, scale efficiency, gross capacity utilization and capacity utilization. Tables 7.6 and 7.7 show the average contribution of the productivity components to the growth. Change in productivity for each province over the periods 1990 to 2000, and 2000 to 2012, respectively.  

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23 The yearly cumulative productivity change and the decomposed sources of change for each province are presenting at Appendix C.
CHAPTER 7. RESULTS AND DISCUSSION

Table 7.6 Average change in multifactor productivity and its components by province (%), 1990-2000

<table>
<thead>
<tr>
<th>Province</th>
<th>MFP&lt;sub&gt;c&lt;/sub&gt;</th>
<th>TC</th>
<th>SE&lt;sub&gt;c&lt;/sub&gt;</th>
<th>gCU&lt;sub&gt;c&lt;/sub&gt;</th>
<th>CU&lt;sub&gt;c&lt;/sub&gt;</th>
<th>PTE&lt;sub&gt;c&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newfoundland</td>
<td>-4.3</td>
<td>-2.1</td>
<td>-2.4</td>
<td>-3.9</td>
<td>-5.7</td>
<td>-1.2</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>6.7</td>
<td>4.8</td>
<td>2.4</td>
<td>9.2</td>
<td>-9.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>2.7</td>
<td>1.3</td>
<td>0.4</td>
<td>4.3</td>
<td>1.4</td>
<td>2.0</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>1.8</td>
<td>1.7</td>
<td>0.5</td>
<td>0.3</td>
<td>-0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Quebec</td>
<td>-1.3</td>
<td>0.5</td>
<td>-0.2</td>
<td>-2.0</td>
<td>-1.0</td>
<td>-1.4</td>
</tr>
<tr>
<td>Ontario</td>
<td>1.1</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Manitoba</td>
<td>5.8</td>
<td>2.2</td>
<td>0.4</td>
<td>5.7</td>
<td>-1.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>10.1</td>
<td>4.2</td>
<td>0.9</td>
<td>8.3</td>
<td>0.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Alberta</td>
<td>5.2</td>
<td>2.3</td>
<td>0.0</td>
<td>2.9</td>
<td>-0.6</td>
<td>2.9</td>
</tr>
<tr>
<td>British Columbia</td>
<td>1.4</td>
<td>1.3</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Notes: 1. Appendix A provides a detail information about each component of Malmquist productivity index by province for each year.

2. MFP<sub>c</sub> is multifactor productivity change, TC is technical change, SE<sub>c</sub> is scale efficiency change, gCU<sub>c</sub> is gross capacity utilization change, CU<sub>c</sub> is capacity utilization change. PTE<sub>c</sub> is pure technical efficiency change.

3. Capacity utilization change measures the change in the degree of capacity utilization from time t to time t+1; all of the other changes evaluate the effects from time t+1 to time t.

4. The contribution of pure technical efficiency change can be found by dividing gross capacity utilization change by net capacity utilization change (i.e. PTE<sub>c</sub>=gCU<sub>c</sub>/CU<sub>c</sub>). The detail explanation can be found in section 5.4.1.

Table 7.6 presents the average multifactor productivity change and its components by province between 1990 and 2000. The results show technical change is one of the main drivers of productivity growth for most provinces, except Newfoundland. Nova Scotia, Ontario and British Columbia had around 1.2% technical progress in their
CHAPTER 7. RESULTS AND DISCUSSION

food processing, whereas technical progress for Quebec was 0.5%. Prince Edward Island, Manitoba, Saskatchewan and Alberta all exhibited higher technical progress. The technical progress for most provinces in the pre-2000 period may have been facilitated by broadly favorable economic conditions.

Compared to the effect of technical progress, scale efficiency seems to have made a lower contribution to productivity growth. Note, scale efficiency change was not important for Ontario as it operated at optimal scale during 1990 and 2000. Scale efficiency change had a relatively low contribution for Alberta and British Columbia with only 0.5% increase, while Newfoundland and Prince Edward Island were the only provinces that experienced considerable change in scale efficiency. The scale efficiency for Newfoundland decreased by 2.4%, whereas for Prince Edward Island scale efficiency increased by 2.4%.

With regards to gross capacity utilization change, Manitoba, Saskatchewan and Alberta have had higher improvements relative to other provinces. In contrast to the Prairie provinces, the decline in gross capacity utilization for Newfoundland and Quebec contributed negatively to productivity growth. Capacity utilization had an important contribution to productivity growth. In section 7.2, we find the Atlantic provinces experienced a considerable decrease in capacity utilization, in particular for Prince Edward Island. The change in capacity utilization brought considerable negative effects for Newfoundland, Prince Edward Island, and New Brunswick’s productivity growth. Further, the food industry’s productivity in Quebec, Manitoba, and Alberta food also recorded a negative effect from the improvement in capacity utilization. Change in
capacity utilization contributed positively to productivity growth in Nova Scotia and Saskatchewan.

Table 7.7 Average change in multifactor productivity and its components by province (%), 2000-2012

<table>
<thead>
<tr>
<th>Province</th>
<th>$\text{MFP}_c$</th>
<th>TC</th>
<th>$\text{SE}_c$</th>
<th>$\text{gCU}_c$</th>
<th>$\text{CU}_c$</th>
<th>$\text{PTE}_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newfoundland</td>
<td>1.9</td>
<td>-1.6</td>
<td>2.9</td>
<td>6.5</td>
<td>2.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>-1.8</td>
<td>-0.7</td>
<td>-0.8</td>
<td>0.6</td>
<td>-18.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>-3.2</td>
<td>-1.4</td>
<td>0.1</td>
<td>-4.8</td>
<td>-4.4</td>
<td>-1.3</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>-1.1</td>
<td>-0.1</td>
<td>0.8</td>
<td>-2.8</td>
<td>-2</td>
<td>-1.5</td>
</tr>
<tr>
<td>Quebec</td>
<td>-0.5</td>
<td>-1</td>
<td>-0.6</td>
<td>2.3</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Ontario</td>
<td>-2.2</td>
<td>-1.3</td>
<td>-0.8</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Manitoba</td>
<td>-0.1</td>
<td>-0.1</td>
<td>0</td>
<td>2.5</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>-0.7</td>
<td>-0.8</td>
<td>0.2</td>
<td>2.3</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Alberta</td>
<td>-0.7</td>
<td>-1.3</td>
<td>-0.3</td>
<td>1.7</td>
<td>0.4</td>
<td>1.1</td>
</tr>
<tr>
<td>British Columbia</td>
<td>-0.6</td>
<td>-0.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Notes: 1. Appendix A provides a detail information about each component of Malmquist productivity index by province for each year.

2. $\text{MFP}_c$ is multifactor productivity change, TC is technical change, $\text{SE}_c$ is scale efficiency change, $\text{gCU}_c$ is gross capacity utilization change, $\text{CU}_c$ is capacity utilization change. $\text{PTE}_c$ is pure technical efficiency change.

3. Capacity utilization change measures the change in the degree of capacity utilization from time $t$ to time $t+1$; all of the other changes evaluate the effects from time $t+1$ to time $t$.

4. The contribution of pure technical efficiency change can be found by dividing gross capacity utilization change by net capacity utilization change (i.e. $\text{PTE}_c = \frac{\text{gCU}_c}{\text{CU}_c}$). The detail explanation can be found in section 5.4.1.

Table 7.7 presents the decomposed results of productivity between 2000 and 2012. The results reflect the opposite situation compared to the 1990-2000 period for technical
change: every province experienced a decline in technical change. Technical deterioration had a higher negative contribution to the aggregate productivity change. Regarding scale efficiency, Ontario was not operating at optimal operational scale compared to the pre-2000 period and scale inefficiency is for the productivity growth slowdown in Ontario. Prince Edward Island, Quebec and Alberta’s productivity slowdown were also caused by a decline in scale efficiency. Gross capacity utilization in the 2000-2012 period has contributed the most to productivity growth across provinces, except Ontario and British Columbia where the gross capacity utilization remained unchanged. Nova Scotia and New Brunswick’s productivity growth slowdown is driven by the decline in gross capacity utilization and capacity utilization. By contrast, the remaining provinces experienced a considerable increase in gross capacity utilization, meaning gross capacity utilization change contributed positively to productivity growth.

Finally, the change in capacity utilization had less effect on productivity growth than the other sources for most provinces, except for Prince Edward Island, Nova Scotia and New Brunswick. These three provinces are the only provinces that experienced considerable drops in capacity utilization in the post-2000 period, meaning the decline in capacity utilization in these provinces resulted in productivity deterioration. On the other hand, change in capacity utilization contributed positively to Quebec, Manitoba, Saskatchewan and Alberta’s productivity growth with average annual value of 0.6%.

In sum, technical change is the main driver of productivity improvement or deterioration for each province. This finding is consistent with previous studies (e.g., Sowlati and Vahid, 2006). Gross capacity utilization change is the other important factor that contributed to productivity growth in most provinces, with the exception of Ontario.
and British Columbia. Overall, changes in gross capacity utilization contributed positively to productivity growth over the study period. Capacity utilization change and scale efficiency change contributed less to productivity growth than the other two sources. Slowdown in the Atlantic region’s productivity growth is mainly caused by capacity under-utilization.

### 7.3.3 Capacity Utilization and Productivity

I use a fixed effect (FE) and random effect (RE) model to examine the effect of capacity utilization on productivity. In particular, the estimation measures the proportion of variation in MFPG explained by capacity utilization. The Hausman specification test is employed to choose between the FE and RE models: if the $p$-value for the Hausman test is less than .05, it implies both models yield inconsistent coefficients and rejects the random effects model in favor of the fixed effects model, whereas if $p>.05$ both methods yield “similar” coefficients and random effects model is more appropriate.
Table 7.8 Parameter estimates of the effect of change in capacity utilization on productivity growth

<table>
<thead>
<tr>
<th></th>
<th>(FE)</th>
<th>(FE)</th>
<th>(RE)</th>
<th>(RE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$MFP_C$</td>
<td>0.270***</td>
<td>0.279***</td>
<td>0.274***</td>
<td>0.283***</td>
</tr>
<tr>
<td>$CU_c$</td>
<td>(0.047)</td>
<td>(0.046)</td>
<td>(0.467)</td>
<td>(0.045)</td>
</tr>
<tr>
<td>Year&gt;1999</td>
<td>-0.052***</td>
<td>-0.052***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-0.019)</td>
<td>(-0.018)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year&gt;2007</td>
<td>0.009</td>
<td></td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.217)</td>
<td>(0.214)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.00577</td>
<td>0.034***</td>
<td>0.00577</td>
<td>0.034***</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.013)</td>
<td>(0.008)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>Observations</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.140</td>
<td>0.175</td>
<td>0.140</td>
<td>0.175</td>
</tr>
</tbody>
</table>

Notes: 1. FE is fixed effects model. RE is random effects model.
2. $t$ statistics in parentheses * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 7.8 summaries the parameter estimates for the fixed effects and random effects models. For both models, I regress the multifactor productivity change with capacity utilization change for each province over 1990 to 2012. I also include two dummy variables that capture the effect of two economic conditions changes: the years after 1999 and the years after 2007. Although the estimated coefficients across models have similar values, the $p$-value of the Hausman test is 98.56%, which rejects the null hypothesis. Therefore, the random effects model is more appropriate to use. The estimated $R^2$ shows
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that 14% to 17.5% of the variation in multifactor productivity growth can be explained by the change in capacity utilization\(^{24}\). In random effects model 1, the estimated parameter for capacity utilization indicates that a 1% increase in capacity utilization would increase the multifactor productivity by 0.274%. In random effects model 2, the estimated parameter for post-1999 is negative and statistically significant, suggesting the Canadian food processing industry productivity experienced a declined since 2000. The estimated parameter for post-2007 is positive but not statistically significant. This is not consistent with the previous findings of multifactor productivity changes where most provinces had experienced a considerable decline in productivity since 2008.

7.4 Productivity at Five 4-digit NAICS Food Processing Subsectors Level

In this section, I examine productivity at the 4-digit NAICS food processing subsectors for selected provinces and commodities. Table 7.9 shows the average change in productivity and the average effect of the change in technology, scale efficiency, gross capacity utilization and capacity utilization by province from 1990 to 2012.

Most of the provinces exhibited improved productivity in the animal food processing industry, except Ontario: New Brunswick experienced higher productivity growth with average number of 5% per year, followed by 3.7% for Saskatchewan, 3.2% for Alberta, 2.6% for Nova Scotia, 1.5% for British Columbia and Quebec, and 0.6% for Manitoba. Ontario’s animal food processing sector had a considerable decrease of 2.4%

\(^{24}\) I also use random effects model to regress the multifactor productivity growth with all four sources of productivity change for each provinces over 1990-2012. The estimated \(R^2\) shows that 98.53% of the change in productivity can be explained by capacity utilization change. Detailed information can be found in Appendix D.
per year, which largely reflects the productivity drop in the post-2000 period. In particular, the Ontario animal food processing industry experienced a large productivity deterioration after 2003 which could be attributable to the outbreak of bovine spongiform encephalopathy and the resultant decline in the demand for Canadian meat products. The main driver of productivity growth in the animal food processing productivity growth is technical change. Scale efficiency change plays important role in enhancing productivity growth in Quebec, Ontario and Saskatchewan, while change in capacity utilization contributed negatively to Saskatchewan’s productivity growth. Saskatchewan’s capacity utilization was unstable over the study period, but the level of its capacity utilization increased from the average number of 41% in the pre-2000 period to the average number of 60% in the post-2000 period.

In the grain and oilseed product processing industry there is considerable variation in productivity growth across provinces. Manitoba has the highest productivity growth with 9.6% annual increase rate and Alberta’s productivity growth was also considerable at 7.9% per year. The productivity growth in Saskatchewan, with an average increase rate of 1.2% per year, is markedly lower than Manitoba and Alberta. Over the same period, the productivity in grain and oilseed processing industry in Ontario decreased. Manitoba’s productivity growth is driven by an increase in technical change, scale efficiency and capacity utilization. Capacity utilization in Manitoba was increased from an average level of 65.6% in the pre-2000 period to an average level of 100% in the post-2000 period. The average effect of capacity utilization change shows negatively on Manitoba’s productivity growth due to fluctuations in capacity utilization in the pre-2000 period and the unchanged capacity utilization in post-2000 period. Manitoba’s grain and
oilseed processing industry experienced considerable growth in productivity, which might be explained by the fact that Manitoba is dominated by large operations in wheat, oat and feed milling, oilseed crushing and flax milling operations. In particular, Manitoba is one of the leading global suppliers of milled grain and oilseed products (Western Economic Diversification Canada, 2011). Two years, 1995 and 1997, made particularly large contributions to Manitoba’s productivity growth. The Western Grain Transportation Act was removed and North American Free Trade Agreement was signed around that time, which could have stimulated the growth of Manitoba’s grain and oilseed business.
Table 7.9 4-digit NAICS food processing subsectors’ average change in productivity and its decomposition by province (%), 1990-2012

<table>
<thead>
<tr>
<th>Sector</th>
<th>Province</th>
<th>MFP&lt;sub&gt;C&lt;/sub&gt;</th>
<th>TC</th>
<th>SE&lt;sub&gt;C&lt;/sub&gt;</th>
<th>gCU&lt;sub&gt;C&lt;/sub&gt;</th>
<th>CU&lt;sub&gt;C&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>animal food</td>
<td>Nova Scotia</td>
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</tr>
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<td>1.9</td>
<td>3.2</td>
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<tr>
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Although New Brunswick, Quebec and Ontario’s dairy product processing industry have seen a considerable growth in productivity, dairy processing experienced lower productivity growth than other food processing subsectors. The productivity improvement in dairy product processing was mainly driven by technical progress and scale efficiency and, in fact, the change in gross capacity utilization and capacity utilization contribute negatively to Nova Scotia and Quebec’ productivity growth. The average level of capacity utilization in dairy sector is 96%, which is higher than 85% for animal food sector, 89% for grain and oilseed sector, 94% for meat food sector and 92% for seafood preparation sector. The Canadian dairy sector is regulated under supply management, which means the output of dairy processing industry is relatively stable over time. At the same time, the stable growth in dairy processing industry output may reduce a producers’ incentive to invest in technical development.

Meat food processing industry has seen variation in productivity growth across provinces with Nova Scotia and Manitoba experiencing considerable growth with annual rates of 5.4% and 4.8%, respectively. Technical progress is again the main contributor to productivity growth. In fact, changes in capacity utilization contributed negatively to Quebec, Manitoba, Alberta and British Columbia’s productivity growth. Scale efficiency and gross capacity utilization contribute less to productivity growth than other factors. Alberta is the only province which experienced productivity deterioration over the study period, likely caused by considerable technology deterioration over 2003-2004 where the technology variable may capture the disruption in trade of Canadian cattle and beef products due to BSE. To be more specific, since the first case of BSE was found in Alberta in May 2003, 34 countries (including the U.S.) immediately closed their borders
CHAPTER 7. RESULTS AND DISCUSSION

to Canadian live cattle and beef products. At the end of 2003 important markets such as the U.S. Mexico and Russia partially reopened their borders, but only for boneless beef products. The outbreak of BSE in Canada significantly reduced the global demand for Canadian live cattle and beef products with persistent effects lasting for years (LeBanc 2008, Statistics Canada 2007). The restricted import of Canadian beef products has also resulted in limited slaughter capacity (Statistics Canada, 2007). The average level of capacity utilization in the Alberta meat food processing industry experienced a particularly sharp decline: from 99% in the pre-2000 period to 87.5% in the post-2000 period, where the average capacity utilization between 2003 and 2004 was only 82%.

The seafood processing industry in Prince Edward Island, Nova Scotia and British Columbia experienced considerable growth in productivity over the study period, with annual growth rates of 3.6%, 1% and 3.1% respectively. During the same time, New Brunswick seafood processing sector saw a considerable decrease in of 2.1% per year, mainly due to the drop in productivity during the pre-2000 period. Technical change is the main contributor to productivity growth in all provinces except Newfoundland. Dumas (1992) suggests technical change is one of the most important factors determining the food processing industry’s productivity growth. Adoption of more automated technologies will allow more effective use of production inputs and, consequently, increase productivity. Atlantic Canada Opportunities Agency\(^\text{25}\) documents that “Atlantic Canada’s rich tradition in fisheries and its excellent transportation infrastructure (air, sea and land) continue to support the fisheries and aquaculture industry as it develops innovative harvesting, processing and conservation technologies.”

\(^{25}\) Seafood Industry in Atlantic Canada.
efficiency is one main reason for Prince Edward Island’s productivity growth, whereas a decline in capacity utilization contributed negatively to Newfoundland and Nova Scotia’s productivity growth.

In sum, most provinces experienced an increase in productivity for selected food processing subsectors over the study period where technical progress is the most important factor driving productivity growth. Over the study period, a decline in capacity utilization contributes negatively to most provinces’ food subsectors’ productivity growth. Although productivity growth is also determined by changes in gross capacity utilization, scale efficiency and capacity utilization, these drivers contribute relatively less to aggregate productivity growth than technical change.
Chapter 8

Summary, Conclusion, and Policy Implications

8.1 Summary

With ongoing changes in the structure and technology, as well as more open global markets, it will be a challenge for the Canadian food processing industry to retain its competitiveness. Meanwhile, the closure, relocation and reopening of food processing plants across Canada provinces in the past few years emphasizes the changing face of the food processing business at the provincial level. Changes in the trade environment, particularly the foreign exchange rate, resulted in different economic conditions for domestic food processors after 2000. The study is motivated by a lack of sufficient knowledge about the economic performance indicators for the Canadian food processing industry. To address this deficiency, this study used data envelopment analysis to estimate the Malmquist productivity index at the 3- and 4-digit NAICS food processing sectors’ over the period 1990 and 2012, and to identify the sources of productivity growth at provincial level. More importantly, I examined the effect of capacity utilization on growth in productivity.

The results provide evidence on the levels of capacity utilization, pure technical efficiency and scale efficiency for each province during the last two decades. Relative to
other provinces, Ontario and British Columbia operate at full capacity over the study period. The average estimated capacity utilization is 96% for Quebec, 91% for Alberta, 85% for Manitoba, 80% for Saskatchewan, 70% for Prince Edward Island and 87% for Nova Scotia. In particular, the Atlantic provinces experienced a considerable decrease in capacity utilization in the post-2000 period whereas Ontario, British Columbia and Prince Edward Island were the benchmark in pure technical efficiency. Manitoba, Saskatchewan and Alberta experienced an upward trend in pure technical efficiency from 1990 to 2012. With the exception of Newfoundland, the Atlantic provinces realized a large decline in pure technical efficiency after 2008. In terms of scale efficiency, most provinces became less scale efficient after 2000, except Nova Scotia, New Brunswick and Manitoba, while Ontario and Quebec’s average scale efficiency were 98% and 96.5%, respectively.

Multifactor productivity growth varies across provinces and declined in most provinces over the post-2000 period consistent with Baldwin et al. (2013). Newfoundland, Nova Scotia, Quebec and Ontario experienced distinct productivity decreases of 0.9%, 0.5%, 0.8% and 0.7% respectively. In contrast, Prince Edward Island, Manitoba, Saskatchewan and Alberta achieved growth in productivity with average annual growth rates of 2.1%, 2.6%, 4.2% and 2%, respectively. Decomposing MFP growth into its component parts revealed that technical change is a dominant factor for growth in aggregate productivity performance. Each province exhibited technical change in the same direction in pre- and post-2000 periods. An increase in capacity utilization and gross capacity utilization were the main sources of productivity growth in the Prairie Province, whereas a decrease in capacity utilization contributed more negatively to productivity growth than other factors in the Atlantic provinces. For Ontario and Quebec,
scale inefficiency was the main source of decline in productivity after 2000 aside from technical change.

At the 4-digit NAICS food processing subsectors, most provinces achieved MFP progress over the study period. The animal food and grain product processing industry maintained relatively high productivity growth compared to other subsectors, while the dairy processing sector the least progress in multifactor productivity. Again, technical change was the most important element that led to productivity growth in each industry and each province. Change in capacity utilization contributed negatively to productivity growth in most food processing subsectors at the provincial level. At the same time, the change in gross capacity utilization and scale efficiency made positive but minor contributions to productivity growth in each subsector.

8.2 Conclusion

According to Statistics Canada, 65% of the total Canadian processed food was exported to the U.S. market in 2012. In other words, all provinces except Ontario and British Columbia had large trade surpluses over the past 20 years where the U.S. market is the main destination for their processed products. William et al. (2014) concluded the growth of Manitoba’s food processing sector largely depends on increasing exports. Therefore, international trade conditions and the relative value of the Canadian dollar are vital to economic growth in the Canadian food processing sector. After 2000, there were significant changes in economic conditions such as appreciation in the Canadian dollar, diminished benefits from the U.S. and North American free trade agreements, and a
depressed world economy since 2007. These changes coincided with the changes in the Canadian food processing sector’s productivity growth before and after 2000 found in this study. The recent fall in the value of Canadian dollar and the recovery of the U.S. economy may signal important information for the Canadian economy, including the food processing industry. The relatively low value of the Canadian dollar will make the Canadian food processors more price competitive on global markets and higher levels of productivity would increase their competitiveness even further.

In this study, greater operational size, higher pure technical efficiency and advanced technology are all identified as important factors contributing to productivity growth in the Canadian food processing industry at the provincial level. Remaining at a higher level of capacity utilization is also important to productivity growth, especially for Atlantic and Prairie regions. In that vein, William et al. (2014) argue higher capacity utilization is necessary for Manitoba pork processors to remain efficient and competitive. Given Canadian’s major trade partner is the U.S., diversifying into other markets may help expand the demand for Canadian processed food, and ultimately enhance capacity utilization and productivity. William et al. also point out that expanding Canada’s export market to other destinations such as Europe and Asia can help to utilize the existing plant capacity. Provincial regulations are also an important way to avoid capacity under-utilization (Sinclari, 2013). Sinclari point out that in recent years, authorities in the Atlantic provinces restricted unprocessed or minimally processed fish export to other countries, which stabilized the local fish processing plants’ capacity. Consequently, increasing the socio-economic benefits of processing and enhancing value-added prior to export may improve the productivity and competitive position of the Canadian food
CHAPTER 8. SUMMARY, CONCLUSION, AND POLICY IMPLICATIONS

processing sector. Another factor cited as effecting the productivity of Canadian manufacturing (Frigon, 2013) is the relative value of the Canadian dollar. To maintain a long-term competitive position from continual real exchange rate fluctuations, firms should actively be involved in production re-scheduling (Schnabel 2011) and diversification of trading partners in the face of real exchange rate changes.

8.3 Policy Implications

The results highlighted technical change as one of the main drivers of the Canadian food processing industry aggregate productivity growth, which suggests private business and public institutions could increase investment in research and development to enhance manufacturing productivity and accelerate technology progress. Investment in research and development (R&D) is expected to provide benefits to food processors, yet AAFC (2015) found the intensity of R&D expenditure in food processing sector is lower than the average for the total manufacturing. The net benefit of expanding investment in R&D is, however, unknown and complex. Further research can examine return on R&D investment and the effect of R&D on productivity growth in the Canadian manufacturing industry.

The thesis found a decline in capacity utilization in the Atlantic provinces, which may reflect the decline in the global demand for processed food (e.g., seafood and French fries). Even though the Prairie provinces attained a significant improvement in capacity utilization, the average level of capacity utilization is still lower than Ontario and British Columbia. Expanding the world market for Canadian food products and increasing import demand for Canadian processed food may help to improve capacity utilization and
overall productivity performance. Besides that, changes in provincial regulations are also an important way to maintain high capacity utilization. For example, loosening inter-provincial agricultural products trade agreements and mandatory processing before export may help enhancing productivity and Canada’s competitive position.

8.4 Limitations of this Study and Suggestions for Future Research

This study uses the primal approach to estimate the Canadian food processing industry’s productivity and capacity utilization. The study does not account for the firm’s underlying profit or cost optimizing behavior due to lack of input and output price information. For example, the primal based capacity utilization may underestimate capacity utilization as compared to the dual based models even though they are highly correlated (Nelson, 1989). Future studies could improve on the current study by estimating cost function or profit function.

Further, the construction of the frontier is based on only ten provinces’ data points, which, limits the degree of freedom. The DEA uses linear programing methods to construct a non-parametric piece-wise frontier (or best-practice frontier) by observed data. The estimated level of efficiency is determined by the performance of most efficient province, which is treated as the benchmark. Therefore, more observations could potentially increase the quality of the frontier used to estimate productivity. For example, future studies may improve on the current study by using plant level data. As Porter (2004) points out, “unless there is appropriate improvement at the microeconomic level, macroeconomic, political, legal and social reforms will not bear full fruit”.
Lastly, this study emphasizes technical change is one of the main drivers of aggregate Canadian food processing industry productivity growth. I suggest future researchers address which factors increase Canadian’s food processors’ productivity growth and the extent of the impact of these factors on productivity. Such factors might include: 1) investment in research and development from domestic private sources, domestic public sources or foreign direct investment; 2) the ownership of the firm, domestic or foreign; 3) the implementation of government policies such as supply management.
Bibliography


Industries.” Department of Economics, Working Paper No. 0905E, University of Ottawa, Ottawa


## Appendix

### Appendix A. Estimate results at provincial Level for 1990-2012

#### A.1. Capacity utilization rate estimates by province and year in (%)

| Province | 1990 | 91  | 92  | 93  | 94  | 95  | 96  | 97  | 98  | 99  | 2000 | 01  | 02  | 03  | 04  | 05  | 06  | 07  | 08  | 09  | 2010 | 11  | 12  |
|----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|
| Nfid     | 96   | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 63  | 88  | 100  | 100 | 100 | 100 | 75  | 100 | 100 | 100 | 100 | 100 | 100 |
| PEI      | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 44  | 73  | 45  | 100  | 100 | 100 | 100 | 44  | 44  | 100 | 53  | 40  | 27  | 31  | 37  | 29  | 37  |
| NS       | 83   | 87  | 97  | 90  | 89  | 88  | 100 | 85  | 94  | 100 | 100  | 100 | 100 | 100 | 94  | 100 | 100 | 85  | 87  | 75  | 73  | 82  | 76  | 67  | 62  |
| NB       | 87   | 88  | 100 | 93  | 95  | 97  | 96  | 100 | 86  | 89  | 86  | 95  | 83  | 79  | 85  | 76  | 74  | 78  | 77  | 76  | 85  | 86  | 68  | 72  |
| Que      | 98   | 99  | 91  | 93  | 94  | 88  | 86  | 88  | 85  | 87  | 89  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Ont      | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Man      | 82   | 80  | 96  | 82  | 76  | 85  | 88  | 85  | 81  | 60  | 82  | 75  | 55  | 60  | 82  | 82  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99  |
| Sask     | 67   | 81  | 90  | 81  | 74  | 83  | 89  | 100 | 100 | 68  | 83  | 64  | 60  | 58  | 67  | 61  | 72  | 79  | 90  | 91  | 92  | 86  | 97  |
| Albt     | 81   | 90  | 84  | 86  | 76  | 85  | 91  | 94  | 89  | 82  | 79  | 84  | 77  | 76  | 87  | 82  | 87  | 89  | 82  | 85  | 87  | 88  | 85  |
| BC       | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Notes: The number equal to 1, it means province’s capital is fully utilized. The number less than 1, it means that province’s capital is underutilized.
A.2. Gross capacity utilization rate estimates by province and year in (％)

|        | 1990 | 91  | 92  | 93  | 94  | 95  | 96  | 97  | 98  | 99  | 2000 | 01  | 02  | 03  | 04  | 05  | 06  | 07  | 08  | 09  | 2010 | 11  | 12  |
|--------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|
| Nfid   | 96   | 100 | 100 | 100 | 100 | 100 | 86  | 100 | 100 | 100 | 63   | 88  | 100 | 100 | 100 | 100 | 75  | 100 | 100 | 100 | 100  | 100 | 100 |
| PEI    | 100  | 100 | 100 | 100 | 100 | 100 | 44  | 73  | 45  | 100 | 100  | 44  | 44  | 100 | 53  | 40  | 27  | 31  | 37  | 29   | 37  | 29  |
| NS     | 83   | 87  | 97  | 90  | 89  | 98  | 88  | 100 | 85  | 94  | 100  | 94  | 90  | 100 | 85  | 87  | 75  | 73  | 82  | 76   | 67  | 62  |
| NB     | 87   | 88  | 100 | 93  | 95  | 97  | 96  | 100 | 86  | 89  | 86   | 95  | 83  | 79  | 85  | 76  | 74  | 78  | 77  | 76   | 85  | 68  |
| Que    | 98   | 99  | 91  | 93  | 94  | 88  | 86  | 88  | 88  | 85  | 87   | 89  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |
| Ont    | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |
| Man    | 82   | 80  | 96  | 82  | 76  | 85  | 88  | 85  | 81  | 60  | 82   | 75  | 55  | 60  | 82  | 82  | 100 | 100 | 100 | 100  | 100 | 100 |
| Sask   | 67   | 81  | 90  | 81  | 74  | 83  | 89  | 100 | 100 | 68  | 83   | 64  | 60  | 58  | 67  | 61  | 72  | 79  | 90  | 91   | 92  | 86  |
| Albt   | 81   | 90  | 84  | 86  | 76  | 85  | 91  | 94  | 89  | 82  | 79   | 84  | 77  | 76  | 87  | 82  | 87  | 89  | 82  | 85   | 87  | 88  |
| BC     | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |

Notes: The number equal to 1, it means province’s variable inputs and capital stock is fully utilized. The number less than 1, it means that province is fully utilizing either the variable inputs or capital stock.
A.3. Pure technical efficiency estimates by province and year (%)

|        | 1990 | 91  | 92  | 93  | 94  | 95  | 96  | 97  | 98  | 99  | 2000 | 01  | 02  | 03  | 04  | 05  | 06  | 07  | 08  | 09  | 2010 | 11  | 12  |
|--------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|
| Nfid   | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 88  | 77  | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |
| PEI    | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |
| NS     | 86   | 87  | 79  | 88  | 94  | 88  | 97  | 100 | 85  | 83   | 100 | 100 | 93  | 100 | 100 | 100 | 83  | 97  | 83  | 87   | 88  | 81  |
| NB     | 98   | 93  | 98  | 93  | 94  | 88  | 83  | 85  | 91  | 74   | 94  | 94  | 78  | 95  | 88  | 95  | 97  | 85  | 79  | 87   | 76  | 77  | 73  |
| Que    | 100  | 100 | 100 | 100 | 100 | 100 | 91  | 088 | 99  | 85   | 85  | 85  | 99  | 93  | 92  | 87  | 94  | 92  | 96  | 99   | 98  | 93  | 96  | 96  |
| Ont    | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |
| Man    | 81   | 74  | 71  | 76  | 80  | 69  | 70  | 90  | 78  | 75   | 100 | 100 | 88  | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |
| Sask   | 79   | 69  | 74  | 75  | 72  | 66  | 90  | 100 | 100 | 82   | 100 | 100 | 88  | 96  | 93  | 88  | 96  | 85  | 92  | 100  | 100 | 100 |
| Albt   | 74   | 79  | 73  | 81  | 93  | 100 | 100 | 93  | 79  | 100  | 92  | 72  | 81  | 94  | 100 | 99  | 93  | 100 | 100 | 98   | 99  | 100 | 100 |
| BC     | 100  | 100 | 94  | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100  | 100 | 100 |

Notes: The number equal to 1, it means province is pure technical efficient. The number less than 1, it means province is pure technical inefficient.
### A.4. Scale efficiency estimates by province and year (%)

|       | 1990 | 91  | 92  | 93  | 94  | 95  | 96  | 97  | 98  | 99  | 2000 | 01  | 02  | 03  | 04  | 05  | 06  | 07  | 08  | 09  | 2010 | 11  | 12  |
|-------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|
| Nfid  | 100  | 100 | 100 | 99  | 86  | 78  | 77  | 83  | 81  | 100 | 72   | 72  | 69  | 75  | 88  | 83  | 86  | 88  | 85  | 100  | 100 | 100 | 98  |
| PEI   | 80   | 81  | 84  | 98  | 95  | 100 | 92  | 58  | 72  | 92  | 85   | 85  | 95  | 68  | 74  | 98  | 77  | 71  | 65  | 72   | 76  | 71  | 67  |
| NS    | 95   | 95  | 94  | 89  | 89  | 88  | 82  | 96  | 85  | 91  | 96   | 96  | 88  | 90  | 100 | 100 | 93  | 95  | 87  | 100  | 99  | 100 | 94  |
| NB    | 89   | 89  | 84  | 86  | 88  | 88  | 83  | 92  | 90  | 90  | 93   | 93  | 92  | 84  | 92  | 93  | 91  | 96  | 91  | 100  | 93  | 100 | 99  |
| Que   | 100  | 100 | 100 | 100 | 100 | 99  | 98  | 100 | 98  | 100 | 97   | 97  | 98  | 99  | 99  | 97  | 93  | 93  | 91  | 89   | 93  | 90  | 90  |
| Ont   | 100  | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100   | 100 | 100 | 94  | 91  | 88  | 97  | 91  | 90  | 88   | 97  | 91  | 90  |
| Man   | 96   | 95  | 96  | 100 | 99  | 100 | 98  | 99  | 99  | 95  | 100   | 100 | 98  | 100 | 100 | 100 | 100 | 100 | 100 | 100   | 100 | 100 | 100 |
| Sask  | 93   | 93  | 93  | 96  | 99  | 99  | 97  | 100 | 100 | 87  | 100   | 100 | 98  | 91  | 93  | 95  | 93  | 92  | 83  | 99   | 100 | 100 | 100 |
| Albt  | 98   | 99  | 98  | 100 | 100 | 100 | 100 | 98  | 96  | 99  | 99   | 100 | 97  | 100 | 100 | 100 | 100 | 100 | 95   | 88  | 98  | 100 | 94  |
| BC    | 100  | 100 | 93  | 100 | 100 | 98  | 97  | 94  | 94  | 100 | 100   | 100 | 100 | 100 | 98  | 94  | 94  | 100 | 100 | 100   | 100 | 100 | 100 |

Notes: The number equal to 1, it means province operates at optimal scale. The number less than 1, it means province is not operate at optimal scale.
**A.5. Multifactor productivity change rates, by province and year in percent (%)**

| Province | 1991 | 92  | 93  | 94  | 95  | 96  | 97  | 98  | 99  | 2000 | 01  | 02  | 03  | 04  | 05  | 06  | 07  | 08  | 09  | 2010 | 11  | 12  |
|----------|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|
| Nfld     | 8.3  | -2.5| -16.5| -14.5| -13.7| -0.3| -0.8| 6.1 | 40.9| -50.0| -5.4| 9.1 | 5.7 | 3.7 | -7.2| 1.0 | 9.6 | 1.9 | 3.3  | 0.4 | -0.9| 1.9 |
| PEI      | 7.7  | 8.5 | 8.6 | 2.3 | 20.2| -14.9| -25.9| 56.9| 5.3 | -1.7 | 13.4| -18.3| 11.7| 25.6| -17.4| 6.2 | -3.7| -0.4 | -4.0| 0.2 | -1.5|
| NS       | 6.9  | -1.6| -2.3| 8.2 | -7.4| 2.5 | 17.9| -12.3| 10.8| 4.5 | -9.4 | 1.7 | -11.4| 5.6 | -4.8| -6.6| -9.7| 15.4| -12.5| 0.0 | 3.5 | -9.7|
| NB       | 0.3  | 7.5 | -8.6| 9.3 | -8.4| -9.0| 10.3| 18.1| -11.5| 10.1| 4.3 | -25.6| 10.0| -3.5| 7.0 | 4.6 | 3.0 | -9.8 | 9.4 | -20.1| 9.8 | -2.3|
| Que      | 8.2  | -0.8| -3.7| 1.0 | -13.9| -4.3| 12.1| 1.5 | 4.5 | -17.5| 14.6| -9.0 | -3.9| -9.8| 3.6 | -2.6| 9.5 | 2.4 | -8.9 | -6.9| 4.1 | 1.4 |
| Ont      | 5.7  | 11.3| -7.1| 0.8 | -1.3| 0.4 | -4.8| 14.1| 7.2 | -15.0| 0.9 | -7.1 | -4.2| -4.6| -2.9| 0.0 | 0.8 | -2.3| -7.6 | 2.6 | -2.0| -0.1|
| Man      | -2.6 | 2.2 | 2.6 | 9.3 | -10.1| -0.3| 34.1| 4.5 | -19.0| 36.8| -13.9| 0.1 | -7.9| 4.7 | -2.3| 15.1| 14.3| 4.2 | -10.8| -11.2| 6.5 | 0.3 |
| Sask     | -5.4 | 10.8| -3.4| 3.0 | -1.1| 30.5| 29.9| 25.9| -42.7| 53.2| -23.5| -3.7| -16.8| 0.6 | 8.3 | 1.3 | 19.0| 2.0 | -3.1| 8.3 | -0.4| 0.4 |
| Albt     | 14.7 | -3.6| 4.4 | 21.0| 14.1| 1.5 | -10.1| 0.8 | 28.4| -19.1| -21.2| 0.8 | 10.3| 4.0 | -7.0| -2.1| 13.7| -2.6| -13.2| 4.5 | 8.6 | -4.4|
| BC       | -4.5 | -5.3| 9.3 | 11.7| -11.6| -1.1| -5.5| 17.0| 16.0| -11.9| 1.0 | -3.0| -4.7| -12.4| 0.0 | 2.2 | 2.4 | -2.0| -3.5| 3.3 | 4.1 | 5.6 |

Notes: 1. \( \%\Delta \text{MFP} = (\text{MFP} - 1) \times 100\%. \) 2. \( \%\Delta \text{MFP} = (1 + \%\Delta \text{TC}) \times (1 + \%\Delta \text{SE}) \times (1 + \%\Delta \text{gCU})/(1 + \%\Delta \text{CU}) - 1 \)
### A.6. Technical change rates, by province and year in percent (%)

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### A.7. Scale efficiency change rates, by province and year in percent (\%)

| Province | 1991 | 92  | 93  | 94  | 95  | 96  | 97  | 98  | 99  | 2000 | 01  | 02  | 03  | 04  | 05  | 06  | 07  | 08  | 09  | 2010 | 11  | 12 |
|----------|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|
| Nfld     | 0.0  | 0.0 | -1.2| -13.2| -8.9| -1.9| 7.2 | -1.3| 23.3| -27.7| 8.2 | -11.6| 8.9 | 16.2| -5.3| 4.1 | 1.4 | -3.0| 17.9 | 0.0 | -0.9| -1.4|
| PEI      | 0.5  | 4.2 | 16.7| -2.5 | 5.0 | -8.5| -36.3| 24.3| 27.3| -6.9 | 16.4| -4.6 | -28.2| 7.5 | 32.7| -21.0| -8.6| -8.4| 11.6 | 4.8 | -6.7| -4.7|
| NS       | -0.2 | -1.0| -5.2 | -0.3 | -1.8| -6.5 | 18.1| -12.6| 7.7 | -11.5| 3.8 | 2.2 | 11.3 | 0.0 | -6.4| 1.5 | -8.4| 14.9 | -1.0| 0.4 | -5.1|
| NB       | -0.1 | -6.4| 3.0 | 1.8  | -0.3| -4.3 | 9.5 | -1.9| 0.2 | 3.0 | 4.6 | -5.9 | -7.7 | 8.9 | 2.1 | -2.9| 5.4 | -5.3| 10.0| -7.7| 8.1 | -0.4|
| Que      | 0.0  | 0.0 | 0.0 | 0.0  | -1.3| -0.5 | 1.5 | -1.4| 1.4 | -2.0| -0.2| 0.6 | 0.5 | 1.0 | -2.4| -4.3| -0.9| -1.5| -2.0| 5.4 | -4.2| 0.8 |
| Ont      | 0.0  | 0.0 | 0.0 | 0.0  | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Man      | -0.9 | 1.2 | 3.2 | -0.4 | 0.7 | -1.4 | 0.3 | 0.0 | -3.4| 4.8 | -0.7| 0.7 | -2.1| 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sask     | 0.7  | -0.3| 2.7 | 2.8  | 0.0 | -1.7| 3.2 | 0.0 | -12.8| 14.7| -6.1| 4.8 | -7.7| 2.3 | 2.4 | -1.4| -2.3| -9.4| 18.9| 1.3 | 0.0 | 0.0 |
| Albt     | 0.1  | -0.1| 1.4 | -0.2 | 0.3 | 0.0 | -0.5| -1.3| -1.9| 2.6 | 1.0 | -0.1| -2.8| 3.1 | -0.3| -0.4| -4.1| -7.6| 11.1| 2.1 | -5.7|
| BC       | 0.0  | -6.6| 7.1 | 0.0  | -2.1| -0.9| -2.8| 0.1 | 5.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -2.3| -3.0| -0.8| 6.4 | 0.0 | 0.0 |
A.8. Gross capacity utilization change rates, by province and year in percent (%)

| Province | 1991 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 2000 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 2010 | 11 | 12 |
|----------|------|----|----|----|----|----|----|----|----|------|----|----|----|----|----|----|----|----|-----|----|----|
| Nfld     | 4.0  | 0.0| 0.0| 0.0| 0.0| -13.8| 16.0| 0.0| 0.0| -44.8| 22.3| 48.0| 0.0| 0.0| -24.8| 33.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| PEI      | 0.0  | 0.0| 0.0| 0.0| 0.0| -55.9| 65.7| -37.7| 120.0| 0.0| 0.0| 56.3| 1.8| 125.0| -46.5| 24.3| -34.0| 17.2| 17.3| -20.0| 26.4|
| NS       | 4.5  | 2.3| 3.2| 5.0| 3.4| -0.9| 17.0| -27.0| 7.9| 27.0| 0.0| 0.0| 13.0| 15.0| -14.5| 1.7| 29.0| 14.9| -2.8| -4.0| -11.2| 15.0|
| NB       | -4.1 | 20.6| 11.3| 3.6| -5.9| -6.3| 7.7| -8.6| -16.3| 23.4| 10.7| -27.7| 16.5| 0.0| -4.3| -0.7| -7.9| -7.3| 9.3| -2.0| -19.9| 0.0|
| Que      | 1.0  | -8.2| 2.8| 0.9| -15.2| -5.3| 15.8| -18.0| 2.2| 3.8| 29.7| -5.6| -1.8| -5.2| 8.5| -2.8| 4.8| 3.0| -1.9| -4.6| 3.8| 0.0|
| Ont      | 0.0  | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|
| Man      | -10.6| 16.4| -8.7| -3.0| -3.5| 5.6| 24.6| -18.8| -28.3| 82.8| -19.2| -16.1| 8.4| 37.2| -0.8| 22.0| 0.0| 0.0| 0.0| 0.0| 0.0| -1.0|
| Sask     | 5.6  | 18.7| -9.1| -12.7| 3.3| 46.4| 25.0| 0.0| -44.4| 50.0| -32.2| 2.3| -8.0| 11.2| -1.7| 6.2| 17.4| 24.3| 0.9| 1.9| -6.9| 12.6|
| Albt     | 18.4 | -13.5| 13.2| 2.1| 20.5| 6.4| -4.3| -18.4| 16.5| -11.7| -16.0| 1.2| 16.7| 20.0| -6.5| -0.8| 9.7| -7.4| 1.7| 3.4| 2.7| -4.2|
| BC       | 0.0  | -5.7| 6.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0|

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### A.9. Capacity utilization change rates, by province and year in percent (%)

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<td>-11.6</td>
<td>11.8</td>
<td>7.1</td>
<td>3.3</td>
<td>-5.3</td>
<td>-7.9</td>
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</table>

Notes: Capacity utilization change is obtained by dividing the capacity utilization rate in year t+1 by capacity utilization rate in year t.
Appendix B. GAMS Code

In this study, I use General Algebraic Modelling System (GAMS) to estimate each province different efficiency indicators. GAMS is a convenient linear programming system that can edit the constraints which helps to estimate the capacity utilization, pure technical efficiency and scale efficiency. The Table below illustrates the codes written in GAMS for our analysis.

```
1. $oninline
2. set inout /ValueAdd, Energy, Labour, Material, Capital /
3. output(inout) / ValueAdd /
4. input(inout)/ Energy, Labour, Material, Capital /
5. Fixed(inout) / Capital /
6. Var(inout) / Energy, Labour, Material /
7. obs / 1*230 /
8. subobs(obs)/ 1*10 /
9. actobs(obs);
10. alias(subobs, subobs1);

11. table act(obs, inout) input output table
12. $ondelim
13. $include "G:simulation.csv"
14. $offdelim;

15. Variables
16. theta efficiency score
17. weight(obs) weights
18. lambda(obs, var);
19. positive variable weight, lambda;

20. equations
21. constr1(output, obs) DEA constraint for each output
22. constr2(input, obs) DEA constraint for all inputs
23. constr3(fixed, obs) DEA constraint for fixed input
24. constr4(var, obs) DEA constraint for variable input
25. constr5(var, obs) DEA constraint for variable returns to scale;
26. constr1(output, actobs).. sum(subobs, weight (subobs) * act(subobs, output)) =G= theta*act(actobs,output);
27. constr2(input, actobs).. sum(subobs, weight(subobs)*act(subobs, input)) =l= act(actobs, input);
28. constr3(fixed, actobs).. sum(subobs, weight(subobs)*act(subobs, fixed)) =l= 
```
act(actobs, fixed);
29. constr4(var, actobs). sum(subobs, weight(subobs)*act(subobs, var)) =e=
lambda(actobs, var)*act(actobs, var);
30. constr5(var, actobs).. sum(subobs, weight(subobs)) =E= 1;

31. parameter
32. score1(obs,*) theta estimates
33. score2(obs, var) hold variable input level;

34. model ctedea /constr1, constr2/;
35. model vtedea /constr1, constr2, constr5/;
36. model tecu /constr1, constr3, constr4, constr5/;

37. loop(subobs1, 
38. actobs (obs) = no;
39. actobs(subobs1) = yes;
40. option LP=OSL;
41. solve ctedea maximizing theta using LP;
42. score1(subobs1,"cTE")=theta.l;
43.);

44. loop(subobs1, 
45. actobs (obs) = no;
46. actobs(subobs1) = yes;
47. option LP=OSL;
48. solve vtedea maximizing theta using LP;
49. score1(subobs1,"vTE")=theta.l;
50.);

51. loop(subobs1, 
52. actobs (obs) = no;
53. actobs(subobs1) = yes;
54. option LP=OSL;
55. solve tecu maximizing theta using LP;
56. score1(subobs1,"tecu")=theta.l;
57. score2(subobs1, var)=lambda.l(subobs1, var);
58.);

59. score1(subobs1,"CU")=score1(subobs1,"vTE")/score1(subobs1,"tecu");
60. score1(subobs1,"SE")=score1(subobs1,"cTE")/score1(subobs1,"vTE");

61. file res/G:\teoutput.csv/
62. res.pc=5;
63. res.pw=160;
64. put res;
65. put 'TE','Capout','Capacity','CU',
66. loop(subobs1, put/
67. put score1(subobs1,"cTE"),score1(subobs1,"vTE"),score1(subobs1,"SE"),
    score1(subobs1,"tecu"),score1(subobs1,"CU");
68. putclose res;
Appendix C. Multifactor productivity change and its decomposed components.

C.1. The cumulative productivity change and its decomposed components in Newfoundland
C.2. The cumulative productivity change and its decomposed components in Prince Edward Island
C.3. The cumulative productivity change and its decomposed components in Nova Scotia
C.4. The cumulative productivity change and its decomposed components in New Brunswick
C.5. The cumulative productivity change and its decomposed components in Quebec
C.6. The cumulative productivity change and its decomposed components in Ontario
C.7. The cumulative productivity change and its decomposed components in Manitoba
C.8. The cumulative productivity change and its decomposed components in Saskatchewan
C.9. The cumulative productivity change and its decomposed components in Alberta
C.10. The cumulative productivity change and its decomposed components in British Columbia
Appendix D

Estimated R² for random effect models

Table D.1 Parameter estimates of the effect of change in technology, gross capacity utilization, scale efficiency and capacity utilization on productivity growth

<table>
<thead>
<tr>
<th>Variable</th>
<th>MFP&lt;sub&gt;c&lt;/sub&gt;</th>
<th>MFP&lt;sub&gt;c&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>0.996***</td>
<td>0.992***</td>
</tr>
<tr>
<td></td>
<td>(0.013)</td>
<td>(0.014)</td>
</tr>
<tr>
<td>SE&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.993***</td>
<td>0.991***</td>
</tr>
<tr>
<td></td>
<td>(0.016)</td>
<td>(0.016)</td>
</tr>
<tr>
<td>gCU&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.939***</td>
<td>0.939***</td>
</tr>
<tr>
<td></td>
<td>(0.012)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>CU&lt;sub&gt;c&lt;/sub&gt;</td>
<td>-0.930***</td>
<td>-0.930***</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.015)</td>
</tr>
<tr>
<td>Year&gt;1999</td>
<td>-0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td></td>
</tr>
<tr>
<td>Year&gt;2007</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-0.002*</td>
<td>-0.001</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Observations</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>Overall R²</td>
<td>98.53%</td>
<td>98.53%</td>
</tr>
</tbody>
</table>

t statistics in parentheses * p<0.10, ** p<0.05, *** p<0.01
I use the random effect models to regress the multifactor productivity growth with all the decomposed components for each Canadian province over 1990-2012, and I also regress them separately. The overall $R^2$ presents in the Table D.2. The overall $R^2$ shows how much change in multifactor productivity growth can be explained by all the decomposed components and individual component.

Table D.2 Estimated overall $R^2$ for each random effect model.

<table>
<thead>
<tr>
<th>Decomposed Components</th>
<th>RE1 $MFP_C$</th>
<th>RE2 $MFP_C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$TC, SEc, gCUc, CUc$</td>
<td>98.53%</td>
<td>98.53%</td>
</tr>
<tr>
<td>$TC$</td>
<td>23.73%</td>
<td>23.87%</td>
</tr>
<tr>
<td>$SEc$</td>
<td>28.11%</td>
<td>30.05%</td>
</tr>
<tr>
<td>$gCUc$</td>
<td>33.65%</td>
<td>38%</td>
</tr>
<tr>
<td>$CUc$</td>
<td>14.04%</td>
<td>17.49%</td>
</tr>
</tbody>
</table>

Notes: 1. RE1 is the random effects model regresses the multifactor productivity change with its decomposed components.

2. RE2 is the random effects model regresses the multifactor productivity change with its decomposed components and two time dummy variables: year>1999 and year>2007.